High performance 1.9m station for 23cm EME

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November 25, 2024

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1 Introduction

Discussed here is a high performance 1.9m mesh wire dish station for 23cm EME.

This paper helps quantify the extraordinary performance observed by some 23cm EME stations (e.g., KA1GT) and explores further enhancements to this performance.

A key measure of performance is Antenna Gain divided by Antenna Noise Temperature (G/Ta). We wish to maximize this ratio for best receive performance (G /Ta) while also ensuring transmit performance is not compromised (G).

Results to date have shown that a 1.9m mesh wire dish can outperform most 3m or larger dishes that employ more traditional designs.

Figure 1-1
KB2SA feed with fiberglass struts,
λ/4 dish collar ring, and S12 isolation disk

2 Scope

This paper is focused on improving the 23cm EME performance of an existing 1.9m mesh wire dish having f/D = 0.35.

The radiation pattern is calculated using a full dish with feed simulation in SIMULIA CST Studio Suite®. We then estimate G/Ta at different dish elevation angles by integrating the 3D system feed pattern with a typical 3D noise space.[1]

We start with a very popular RA3AQ septum feed with an abrupt square to round transition[2]. We then vary dish f/D, feed geometry and other current and added system parameters to further optimize G/Ta.

Amateur experiments utilizing the concepts presented in this paper have shown significant performance increase for dish sizes up to 4.88m with similar f/D.

To date, the effects on the performance on smaller (e.g., 1.5m) or larger (e.g., 10m+) dishes with f/D less than 0.3 or greater than 0.4 have not been studied.

3 Acknowledgements

The author would like to acknowledge the following as major contributors to this paper:

- Rastislav (Rasto) Galuscak (OM6AA) for hundreds of hours of simulation
- Rfspin s.r.o. for the use of SIMULIA CST Studio Suite® www.rfspin.com
- Bob Atkins (KA1GT) for his idea on using a square to round waveguide transition
- Paul Chominski (WA6PY) for expert advice, measurements and review
- Mats Bengtsson (KD5FZX) for building the optimized “KB2SA feed” and reporting excellent performance using a solid 4.88M, f/d = 0.39 dish

Figure 3-1
KD5FZX feed with polycarbonate cover for
intrusion mitigation and S12 isolation disk mounting

Figure 3-2
Referenced KA1GT feed

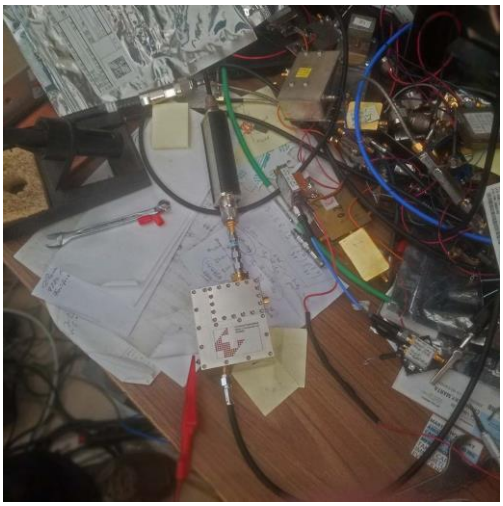

Figure 3-3
WA6PY testing HB9BBD 23cm cavity LNA

4 Why use a 1.9m dish?

This project started from a desire to repurpose an unused telescope pier located on a decorative home patio. As light pollution began to deteriorate optical observation (including the full moon) it was decided to make the moon a friend.

A 1.9m dish was selected as an optimal size – not too small to limit EME contacts (based on observed 1.5m dish QSOs) and not too large to interfere with the normal patio usage and views.

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Figure 4-1
1.9m mesh wire dish installed on existing
telescope pier on decorative home patio

Figures 4-2 through 4-5 illustrate other potential benefits for a 1.9m mesh wire dish.

Figure 4-2
Dish barely moves in 40+ mph winds

Figure 4-3
Easy to tune and service

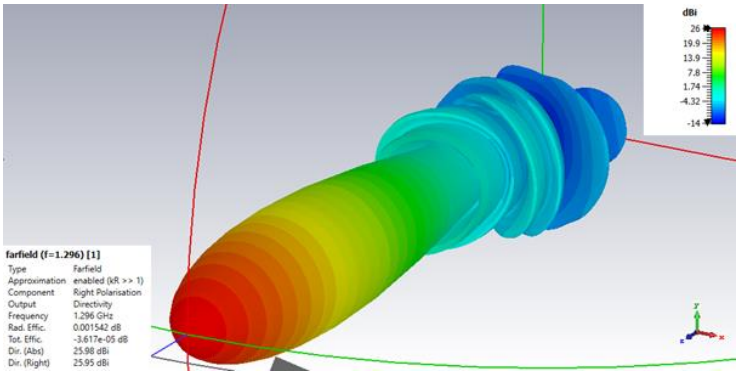


Figure 4-4
Wide beamwidth help hides tracking errors
(e.g., -1 dB when 2° off)

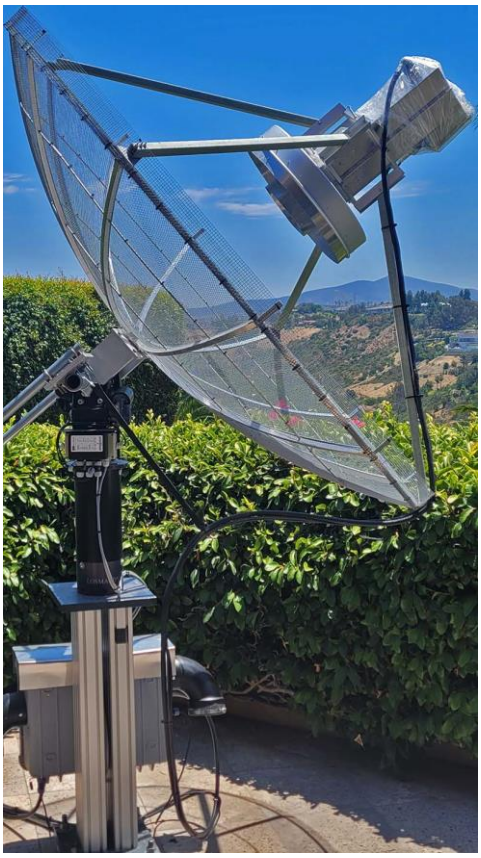


Figure 4-5
Relatively short Tx cable feed (14')
maximizes Tx performance

5 Hardware highlights

This section summarizes the hardware-related parameters that were found to have the highest impact on G/Ts.

Figure 5-1
Feed with square to round taper and S12 isolation disk

5.1 Excellent parabolic surface

One of the most important factors affecting G/Ta is the quality of the parabolic surface.

Envision a deformed telescope mirror resulting in a blurry image. A dish focusing RF at 23cm has a similar behavior. Folks often complain they can't find a clear sun noise peak when moving their feed in or out. Or when they expand their dish size, they often find a marginal performance improvement or no improvement at all.

Ruze's equation (685.81 * (ε/λ)^2) estimates gain loss in dB due to RMS surface errors (ε). If λ = 230 mm and ε = 5 mm, loss = 0.3 dB for just a 5 mm (0.2") RMS surface error.

The effort to estimate the gain loss is usually far more complex than the effort to fix it.

Figure 5-1 plots the shape of a 1.9m f/D = 0.35 mesh wire dish designed and manufactured by RF HAMDESIGN. When compared to the desired $y = ax^2$ shape, very little deviation is seen with the dish pointing at 30° or 90°.

If "a" is selected for the best fit, we can calculate the actual focal point (f) and f/D where D is the dish diameter.

- f = 1 / (4*a) = .692m
- D = 1.92m
- f/D = 0.36

	X	Y (90°)	Y-Bias (90°)	Y=AX^2 (90°)
2	-36	13.125	11.625	11.7936
3	-34	11.75	10.25	10.5196
4	-32	10.75	9.25	9.3184
5	-30	9.625	8.125	8.19
6	-28	8.625	7.125	7.1344
7	-26	7.625	6.125	6.1516
8	-24	6.75	5.25	5.2416
9	-22	5.875	4.375	4.4044
10	-20	5	3.5	3.64
11	-18	4.375	2.875	2.9484
12	-16	3.75	2.25	2.3296
13	-14	3.25	1.75	1.7836
14	-12	2.75	1.25	1.3104
15	-10	2.375	0.875	0.91
16	-8	2	0.5	0.5824
17	-6	1.75	0.25	0.3276
18	-4	1.625	0.125	0.1456
19	-2	1.5	0	0.0364
20	0	1.5	0	0
21	2	1.5	0	0.0364
22	4	1.625	0.125	0.1456
23	6	1.75	0.25	0.3276
24	8	2	0.5	0.5824
25	10	2.375	0.875	0.91
26	12	2.75	1.25	1.3104
27	14	3.125	1.625	1.7836
28	16	3.75	2.25	2.3296
29	18	4.375	2.875	2.9484
30	20	5	3.5	3.64
31	22	5.75	4.25	4.4044
32	24	6.625	5.125	5.2416
33	26	7.5	6	6.1516
34	28	8.75	7.25	7.1344
35	30	9.75	8.25	8.19
36	32	11	9.5	9.3184
37	34	12.125	10.625	10.5196
38	36	13.625	12.125	11.7936

Bias:	1.50	inches	
A:	0.0091	adjust for best fit	
D:	75.50	inches(measured)	1.92m
f/D (spec):	0.35		
f (calc):	26.43	inches	
f (actual):	27.47	inches	
f/D (actual):	0.364		

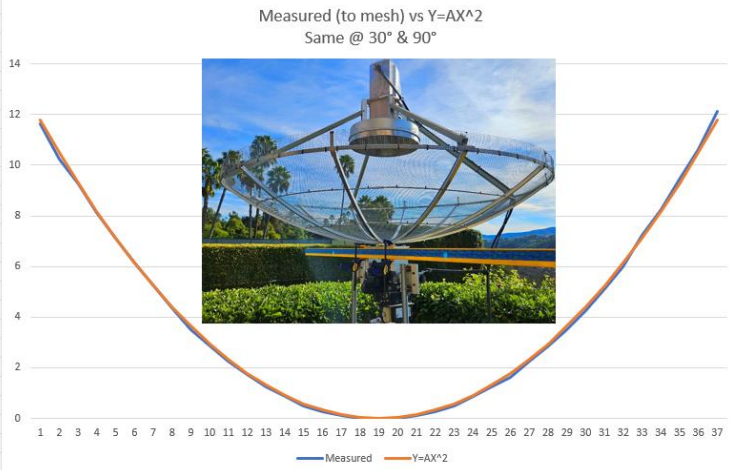


Figure 5.1-1
1.9m f/D = 0.35 mesh wire dish from RF HAMDESIGN

5.2 Loss between feed receive probe and LNA input

Every dB of loss between the feed receive probe and the LNA input adds to the LNA noise figure.

If we assume:

- 85° F ambient (300K)
- LNA noise figure = 0.25 dB
- No TX port noise (i.e., S12 is high)
- Relay + connector loss = 0.1 dB
- Antenna noise @ 30° elevation = **12K**

we can calculate:

- Equivalent LNA noise = 300 * (10^((0.25+0.1)/10) – 1) = **25.18K**
- LNA noise = 300 * (10^((0.25)/10) – 1) = **17.78K**

The total receive performance loss for a 0.1 dB relay + connector loss = 10 * LOG [(25.18+12) / (17.78+12)] = **.96 dB.**

For example, if we have only 6 feet of LMR-600 between the feed receive probe and the LNA input (0.3dB), receive sensitivity would be reduced by almost 2.5 dB.

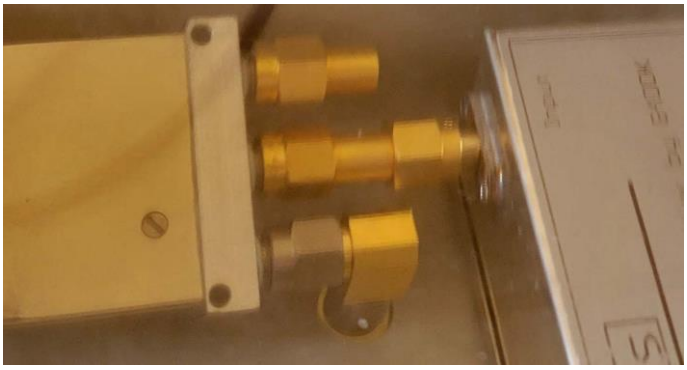


Figure 5.2-1
Low loss Amphenol AD-SMAPSMAP-2, RLC Electronics SR-2MIN-H relay,
and HUBER+SUHNER 32_SMA-50-0-1/111_NE

5.3 Gain loss with mesh

A lightweight and relatively transparent mesh wire dish can perform nearly identical to a solid dish when the mesh openings are small (e.g., opening < λ /10).

Referring to Figure 5.3-1, the gain loss for a mesh wire dish may be calculated[3] for 23cm for popular 6 mm galvanized fence wire mesh:

- Dish Gain Loss (dB) = 10 * LOG (X / (X – 1))
- X = 10 ^ (Mesh Loss (dB) / 10)
- S = S_1 = S_2 = 6 mm
- D = 2*r_1 = 2*r_2 = 0.55 mm
- L = 230 mm (operating wavelength in mm)
- V = LN (1 / (1 - EXP (-π*D/S))) = 1.38
- Mesh Loss (dB) = 20 * LOG (L / (2 * S * V)) = 22.9 dB
- X = 10 ^ (22.9 / 10) = 194.98

Dish Gain Loss (dB) = 10 * LOG (194.98 / (194.98 -1)) = **.022 dB**.

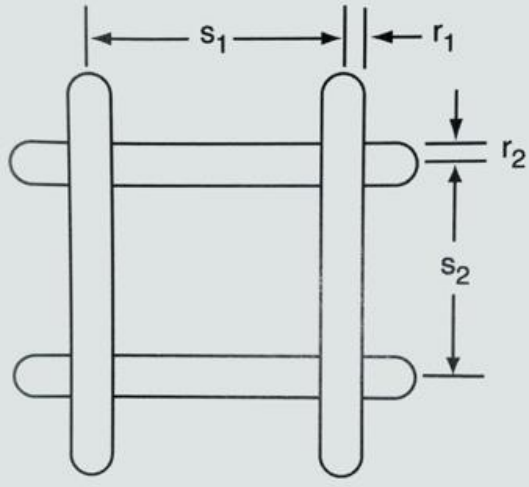


Figure 5.3-1
Mesh wire dimensions

5.4 Between 780 and 910 watts at feed Tx port

A Kuhne MKU PA 23CM – 1200W A power amplifier is enclosed within a Pelican 1550 case and mounted to the pier. An aluminum “roof” helps protect the case from sun and rain.

Air is pulled through the case using downward facing 3” PVC elbows with a 4.7” x 4.7” AC Infinity 110 CFM fan operating at 2600 RPM. The heatsink fans continue to operate while the case interior remains very close to ambient.

Power is measured with a Bird 4410A with a 4410-15 element. A Bird 500-WA-MFN-30 attenuator was measured at -30.7 dB using a calibrated SV4401A Vector Network Analyzer.

The Bird 4410A was calibrated by Bird and specified to be within ±8% full scale.

The measured power levels in the RF chain are:

- **3.4 W** (IC-9700 @ 39%)
- **0.34 W** (5910_N-50-6 10 db/6Ghz/5W H+S attenuator)
- **37 W** (Q5 Signal L2360PA)
- **25 W** (52’ of LMR-600-DB)
- **0.72 W** (Kuhne 1200W, 14’ LMR-600FR, -30.7 dB attenuator)

With ±8% full scale specification, power at the feed is between **780W** and **910W**.

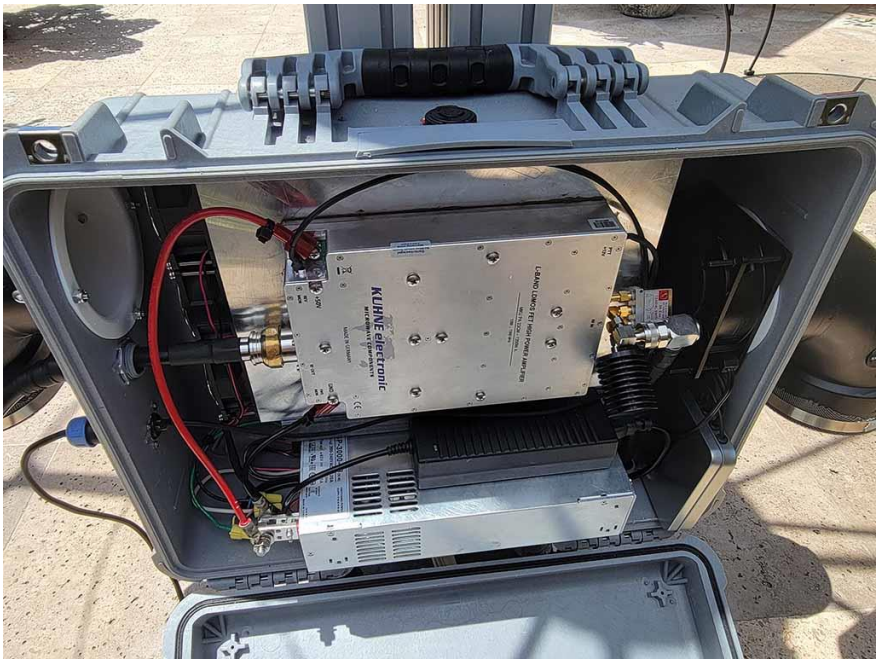


Figure 5.4-1
1200W Kuhne PA inside Pelican Case

Figure 5.4-2
Bird 4410A and 500-WA-MFN-30 attenuator

6 Simulation highlights

Mathematical formulas have been derived to estimate the radiation pattern from a round pipe with a round choke[4]. The formulas assume the choke opening is aligned with the pipe opening.

Precise mathematical formulas for estimating G/Ts for a complete dish plus feed system have not been developed due to complex second-order effects. These effects are significant with a 1.9m dish operating at 1296 Mhz. Numerical analysis has been used to estimate G/Ta with several approximations for specified feeds in much larger dishes.[5]

To quickly and precisely design a very high performance 1.9m system for 1296 Mhz, a high-fidelity simulation environment is needed. Here we use SIMULIA CST Studio Suite®. This is state-of-the-art for microwave antenna simulation in 2024. This simulation tool uses the Finite Integration Technique (FIT) for Maxwell's equations in their integral form using a hexahedral mesh in the time domain.[6]

Simulations in this section include precise 3D models for the dish and feed geometry, feed support struts and feed holder. This includes the feed septum and probes for axial ratio and S12 analysis.

G/Ts is estimated at different dish elevation angles by integrating the 3D system radiation pattern within a typical 3D noise space.[1] Current state-of-the-art electrical noise at 1296 Mhz is included to help focus on optimizing parameters having the highest impact on G/Ts. Excess noise due to electrical losses (e.g., LNA and connectors) can overcome antenna noise, masking potential improvements in the overall G/Ts.

G/Ts calculations are consistent in all simulations for optimizing parameters. The absolute G/Ts values in dB may need to be scaled to compare to other simulations or experiments.[7]

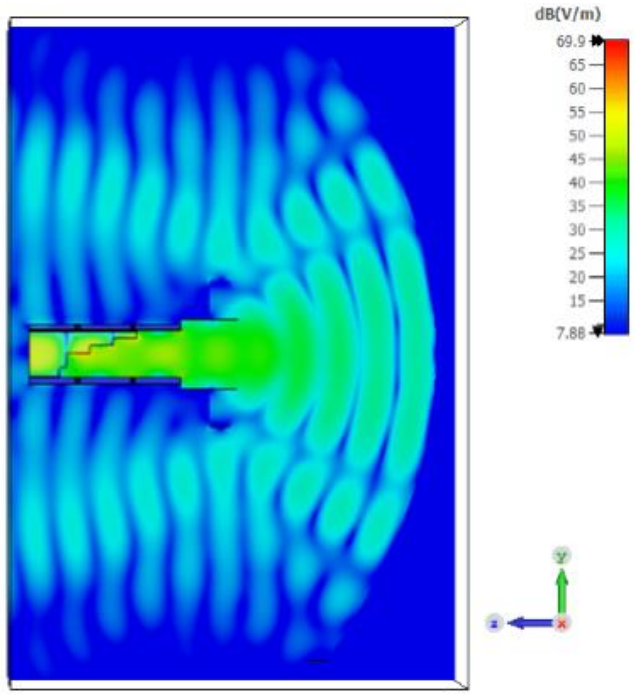


Figure 6-1
Absolute Dish + Feed E-Field in SIMULIA CST Studio Suite®

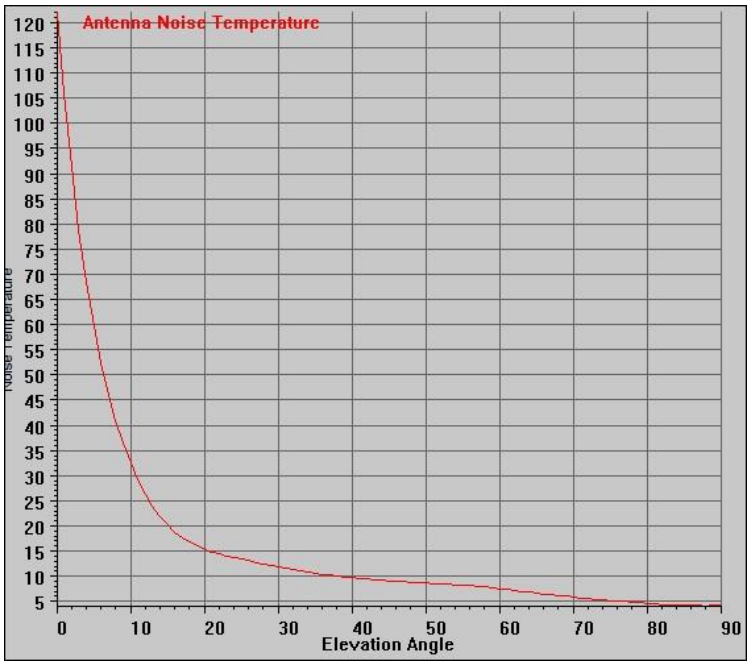


Figure 6-2
Antenna Noise (°K) vs Dish Elevation from ANTC[1]

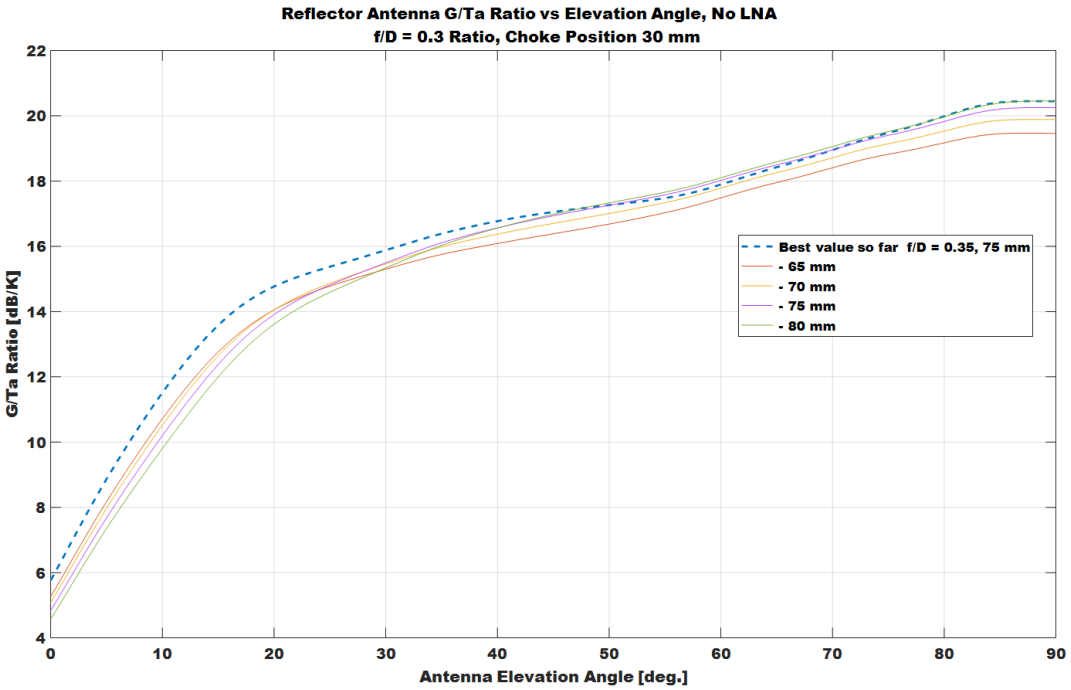

Reflector Antenna G/Ta Ratio vs Elevation Angle, No LNA
f/D = 0.3 Ratio, Choke Position 30 mm
G/Ta Ratio [dB/K]
Antenna Elevation Angle [deg.]
Best value so far f/D = 0.35, 75 mm
- 65 mm
- 70 mm
- 75 mm
- 80 mm

Figure 6-3
G/Ta vs Dish Elevation

We define G/Ts $_{db}$ = 10*LOG [10^(Gmax $_{dBi}$ / 10) / (LNA NF $_{°K}$ + Antenna Noise $_{°K}$)] where LNA NF $_{°K}$ includes connection losses. G/Ta is used when LNA NF $_{°K}$ = 0.

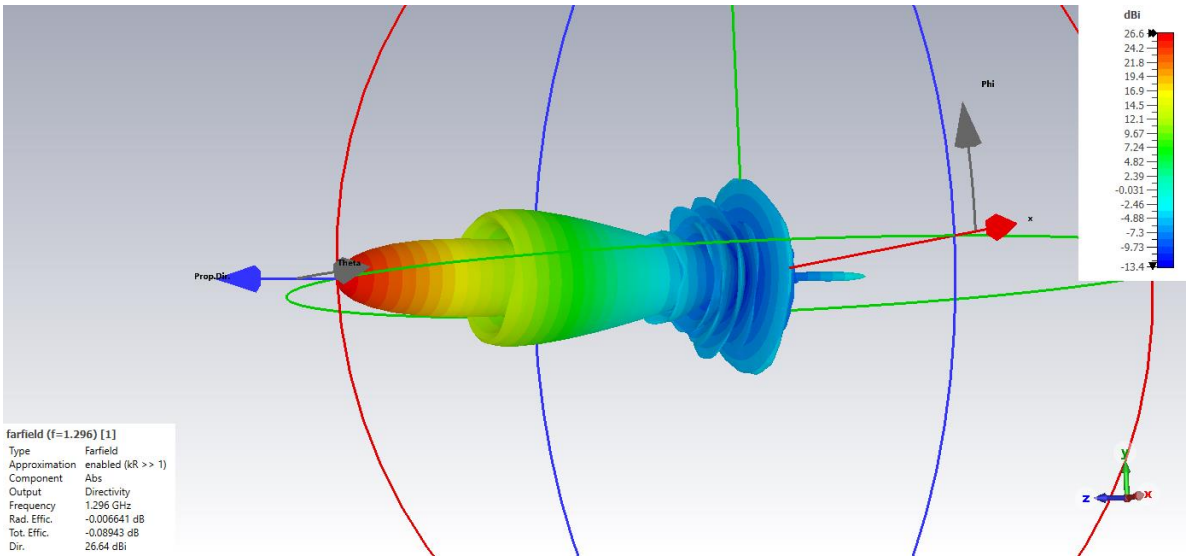


Figure 6-4
3D Farfield dish + feed pattern used by ANTC for Antenna Noise

6.1 Starting feed design

The RA3AQ (2008) feed shown in Figure 6-1 is a popular feed for 23cm EME with dishes having f/D between 3.0 and 4.0.[2]

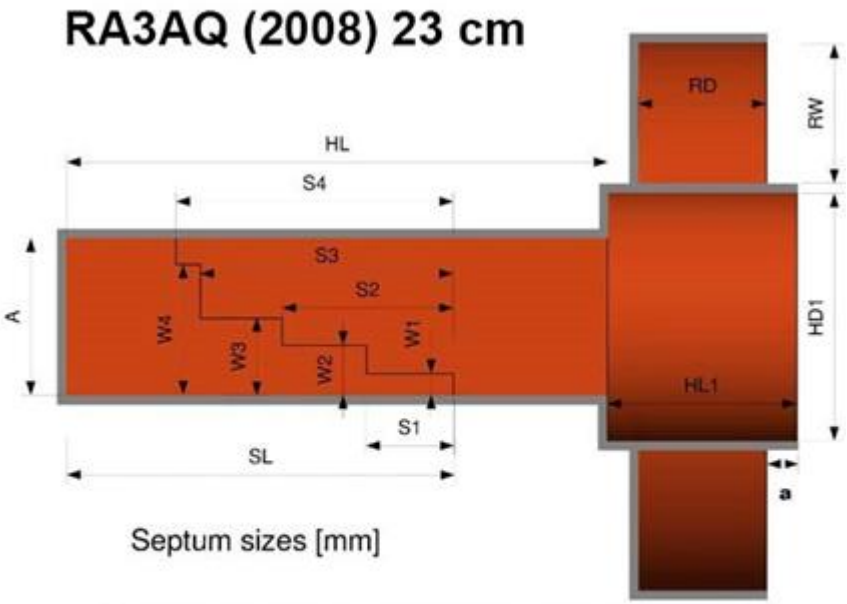
This feed was tested in a 1.9m f/D = .35 dish for nearly a year. During that time, dimension “RD” was changed from 81.0 mm to 60.0 mm and dimension “a” set to 30 mm to maximize the difference between sun and cold sky noise levels.

The feed was constructed from an RF HAMDESIGN feed with changes to the internal septum dimensions to match the specified dimensions.

A noticeable improvement in receive performance (i.e., > 3 dB) was seen when compared to the original square RF HAMDESIGN feed with no choke.

The abrupt square to round transition is unusual. The effects of this transition will be analyzed.

Both a square (no choke) and N2UO feed[8] were tested in a 1.9m f/D = 0.45 dish. The performance of these two systems was similar to the f/D = 0.35 dish with the square (no choke) feed. The N2UO feed was not tested with the f/D = 0.35 dish.



Septum sizes [mm]

F[MHz]	A	HL	SL	W1	W2	W3	W4	S1	S2	S3	S4
1296	143,0	475,0	340,0	22,2	46,9	70,9	117,7	75,6	148,6	220,5	242,3

Output section [mm]

F[MHz]	HD1	HL1	RW	RD
1296	214,0	173,0	118,0	81,0

Figure 6.1-1
Starting feed design

Figure 6.1-2
Original KB2SA system with 1.9m f/D = 0.45
dish and RF HAMDESIGN feed

Figure 6.1-3
1.9m f/D = 0.45 dish with N2UO feed
(currently used by AE5MB)

6.2 RA3AQ feed only (no dish) with and without choke

Figure 6-2-1 illustrates the simulation results for the RA3AQ feed without the dish installed. Simulations are run with and without the choke. We observe:

- The 3 dB beamwidth is reduced from 64.6° to 57.6° when the choke is installed.
- At 72° (near the dish perimeter when feed installed at focus) the pattern is 1 dB lower with the choke.
- The choke significantly lowers energy beyond the dish perimeter. The first sidelobe is lowered 4 dB and moves in approximately 20° when the choke is installed.
- The pattern shape, although narrower with the choke, is relatively unchanged.
- The Axial Ratio (i.e., quality of circular polarization) is very good near boresight with and without the choke.

The relatively unchanged pattern shape is a noteworthy observation. We don't see the boresight dip and widening effect predicted from mathematical analysis of a round feed without an abrupt square to round transition.[4] We'll later see this dip and widening effect is desirable to help increase G/Ts (i.e., more efficient illumination of the dish).

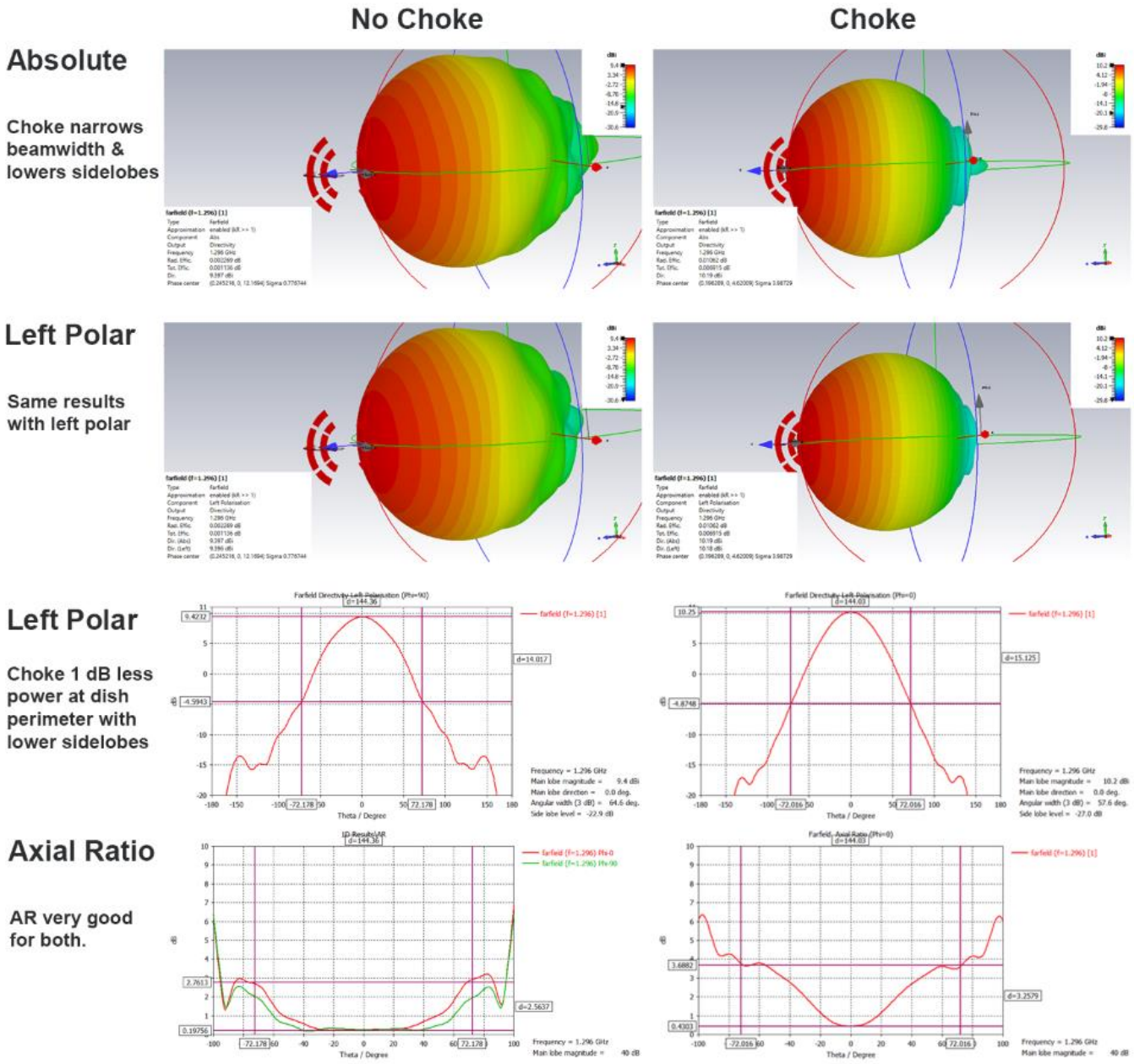


Figure 6.2-1
RA3AQ feed (no dish) with and without choke

6.3 RA3AQ feed and dish with fiberglass mounting struts

Figure 6.3-1 illustrates the RA3AQ feed with the dish in place without mounting strut reflections. When comparing the behavior with and without the choke, we observe the choke increase the low angle sidelobes while the larger angle sidelobes decrease. As a result, antenna noise tends to be similar at low elevations but drops off more rapidly at higher elevations when the choke is added. System gain (G) is almost 1 dB less with the choke. We'll later add typical electrical noise to determine how much this may affect G/Ts.

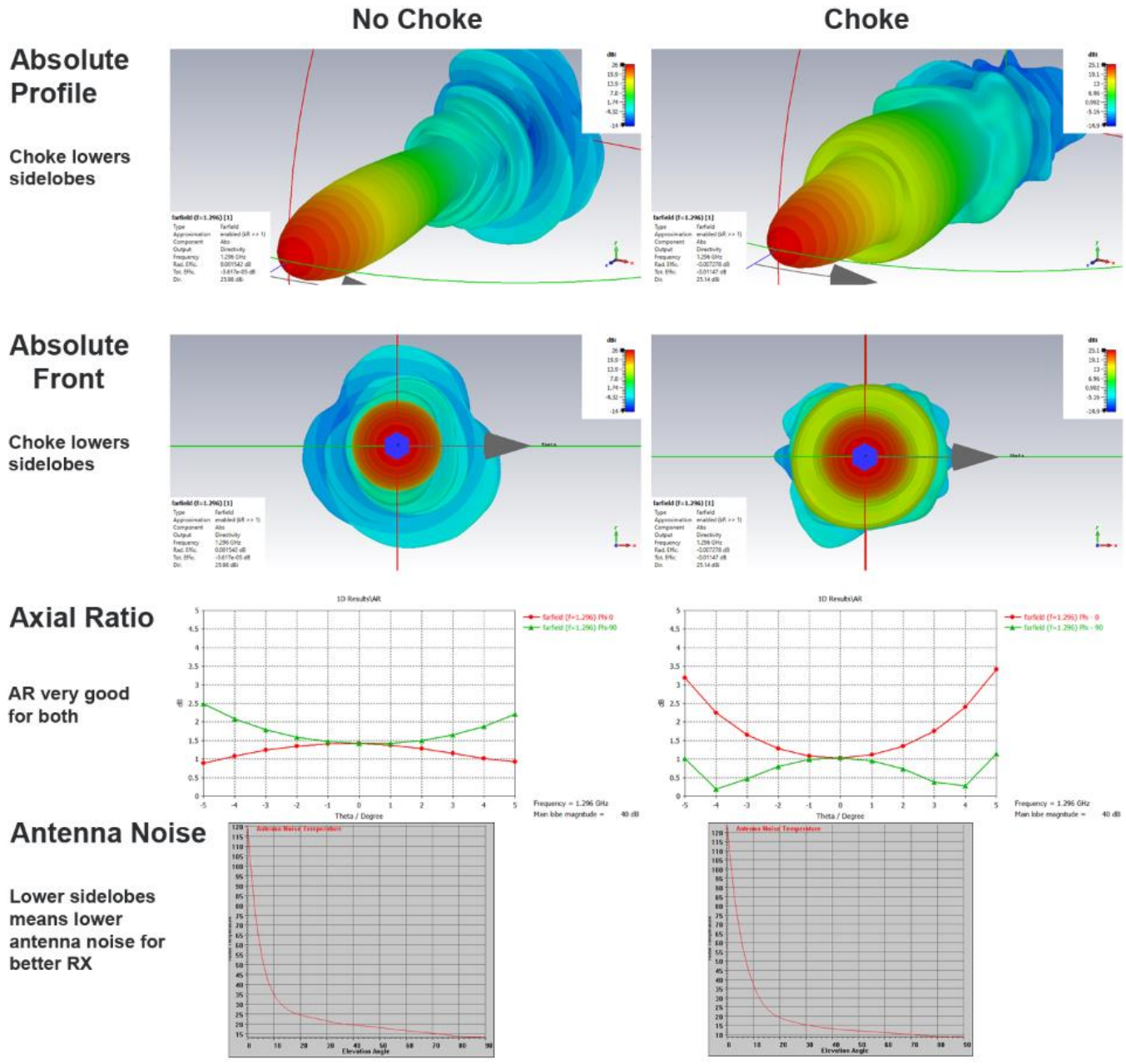


Figure 6.3-1
RA3AQ feed and dish with fiberglass struts

6.4 RA3AQ feed and dish with metal mounting struts

Figure 6.4-1 illustrates the RA3AQ feed with the dish in place with reflections from typical metal mounting struts. We observe:

- Sidelobes increase significantly with no choke. This results in noticeably higher antenna noise at nearly all elevation angles.
- When the choke is added, the effect of the metal struts on sidelobes decreases. This occurs because of the narrower feed pattern and the choke hiding the feed holder and a portion of the metal struts.

- With the choke, antenna noise with metal struts is slightly higher than with fiberglass struts (e.g., +3K @ 30°).

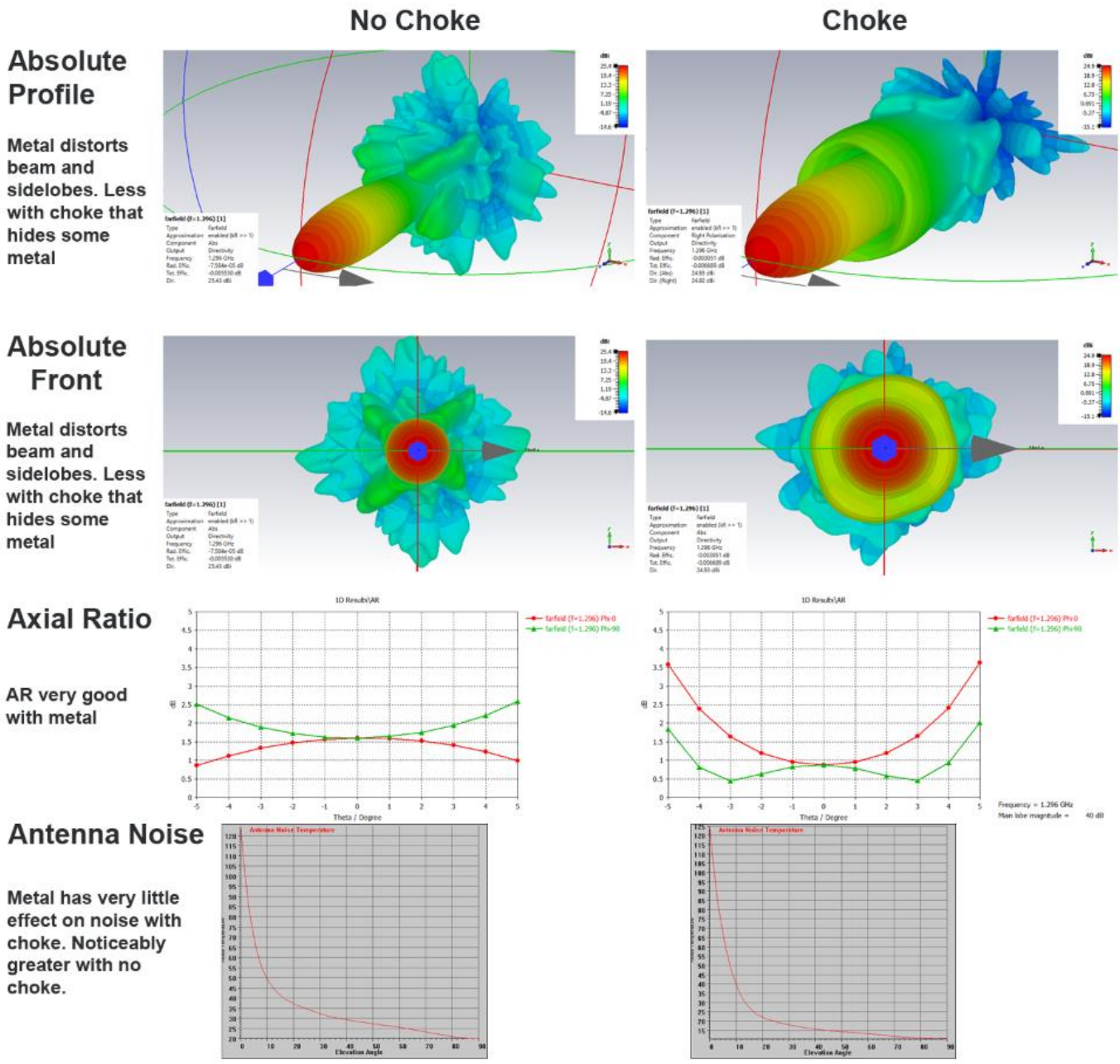

No Choke
Choke
Absolute Profile
Metal distorts beam and sidelobes. Less with choke that hides some metal
Absolute Front
Metal distorts beam and sidelobes. Less with choke that hides some metal
Axial Ratio
AR very good with metal
Antenna Noise
Metal has very little effect on noise with choke. Noticeably greater with no choke.

Figure 6.4-1
RA3AQ feed and dish with metal struts

6.5 RA3AQ feed and dish G/Ts analysis

In this section we analyze the G/Ts performance of the RA3AQ feed and dish system with and without the choke, with and without metal struts, and with and without typical electrical noise. We also analyze antenna gain (G) as it relates to transmission performance.

Figure 6.5-1 illustrates the system performance with no electrical noise (i.e., LNA NF = 0 dB and G/Ts = G/Ta). We observe:

- Transmit performance (G) is more sensitive to feed position when the choke is used. In addition, G is approximately 1 dB less with the choke installed.
- With the choke installed, the focal point is 30 mm inside the feed for highest G/Ts (best receive) and 50 mm inside the feed for highest G (best transmit).
- With no choke installed, the focal point is 10 mm outside the feed for best receive and best transmit.
- For fiberglass struts, no choke yields 1 dB better transmit but 2 dB worse receive than the choke system.

Figure 6.5-2 illustrates the system performance with added electrical noise (i.e., LNA NF = 0.25 dB db and 0.50 dB).

When using fiberglass struts, both G/Ts (receive performance) and G (transmit performance) are the best when no choke is used on the RA3AQ feed. This behavior has also been observed on a real (non-simulated) system.

These results indicate that an RA3AQ feed (with or without a choke) with typical electrical noise may have both lower receive and transmit performance than a circular waveguide feed with choke. This will be confirmed.

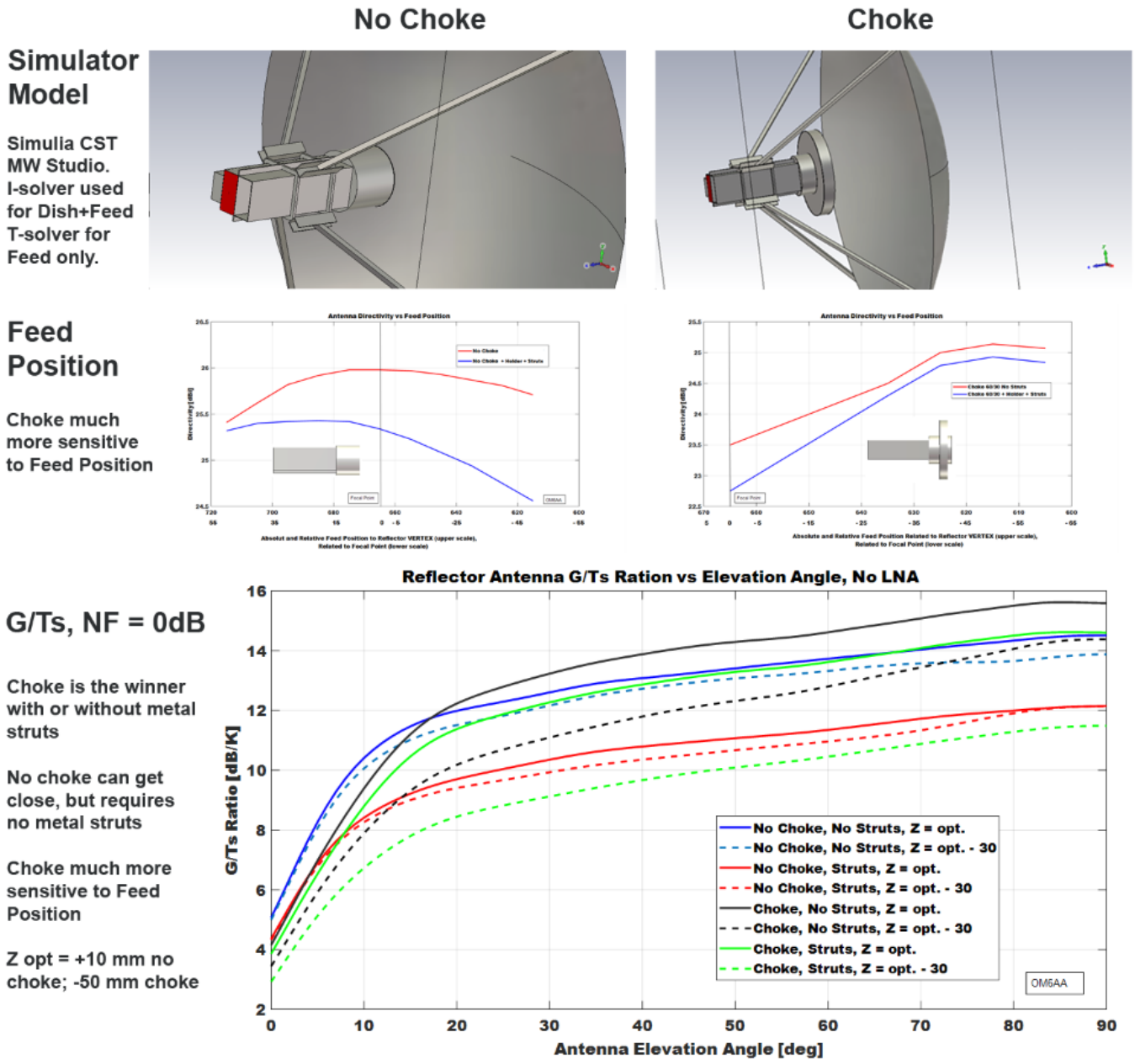

No Choke
Choke
Simulator Model
Simulia CST MW Studio.
I-solver used for Dish+Feed
T-solver for Feed only.
Feed Position
Choke much more sensitive to Feed Position
G/Ts, NF = 0dB
Choke is the winner with or without metal struts
No choke can get close, but requires no metal struts
Choke much more sensitive to Feed Position
Z opt = +10 mm no choke; -50 mm choke
Reflector Antenna G/Ts Ration vs Elevation Angle, No LNA
G/Ts Ratio [dB/K]
Antenna Elevation Angle [deg]
No Choke, No Struts, Z = opt.
No Choke, No Struts, Z = opt. - 30
No Choke, Struts, Z = opt.
No Choke, Struts, Z = opt. - 30
Choke, No Struts, Z = opt.
Choke, No Struts, Z = opt. - 30
Choke, Struts, Z = opt.
Choke, Struts, Z = opt. - 30
OM6AA

Figure 6.5-1
RA3AQ feed and dish G/Ts with NF = 0 dB

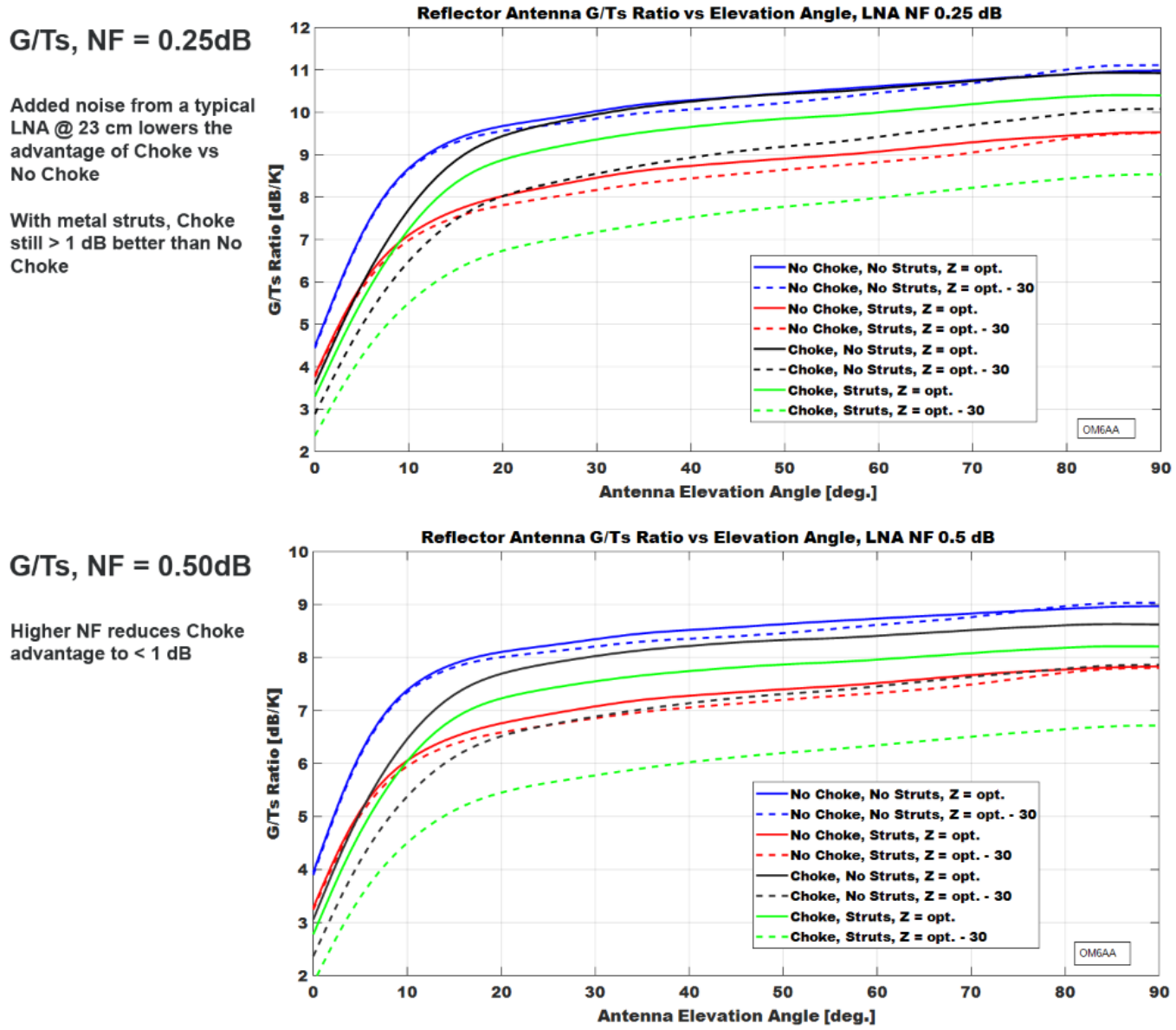

G/Ts, NF = 0.25dB
Added noise from a typical LNA @ 23 cm lowers the advantage of Choke vs No Choke
With metal struts, Choke still > 1 dB better than No Choke
Reflector Antenna G/Ts Ratio vs Elevation Angle, LNA NF 0.25 dB
G/Ts Ratio [dB/K]
Antenna Elevation Angle [deg.]
No Choke, No Struts, Z = opt.
No Choke, No Struts, Z = opt. - 30
No Choke, Struts, Z = opt.
No Choke, Struts, Z = opt. - 30
Choke, No Struts, Z = opt.
Choke, No Struts, Z = opt. - 30
Choke, Struts, Z = opt.
Choke, Struts, Z = opt. - 30
OM6AA
G/Ts, NF = 0.50dB
Higher NF reduces Choke advantage to < 1 dB
Reflector Antenna G/Ts Ratio vs Elevation Angle, LNA NF 0.5 dB
G/Ts Ratio [dB/K]
Antenna Elevation Angle [deg.]
No Choke, No Struts, Z = opt.
No Choke, No Struts, Z = opt. - 30
No Choke, Struts, Z = opt.
No Choke, Struts, Z = opt. - 30
Choke, No Struts, Z = opt.
Choke, No Struts, Z = opt. - 30
Choke, Struts, Z = opt.
Choke, Struts, Z = opt. - 30
OM6AA

Figure 6.5-2
RA3AQ feed and dish G/Ts with NF = 0.25 dB and 0.50 dB

7 Smooth square to round transition

It's well known that a round waveguide with a round choke improves G/Ts for relatively deep dishes (i.e., f/D = 0.3 to 0.4)[9, 10, 11]. It's also somewhat easier to construct a square septum feed rather than a round one. This may be why RA3AQ proposed the addition of the abrupt square to round extension.

We've seen the RA3AQ feed perform better without the choke. This is likely due to the abrupt square to round transition. Although not analyzed in detail, a waveguide discontinuity may be introducing additional modes, beyond TE_{11}, that's preventing a phase change in the coaxial term from causing the desirable flattening of the radiation pattern.[4]

KA1GT may be the first to try a smooth square to round transition to match the desirable behavior of a round septum. Actual EME signal reports indicate this configuration has excellent performance for both transmit and receive. This section will quantify this observation using the simulations techniques described in Section 6.

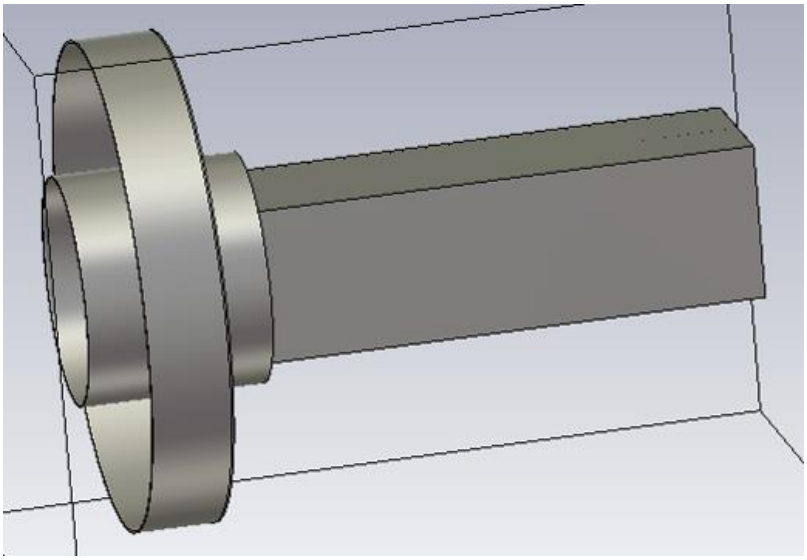


Figure 7-1
RA3AQ feed with abrupt square to round transition

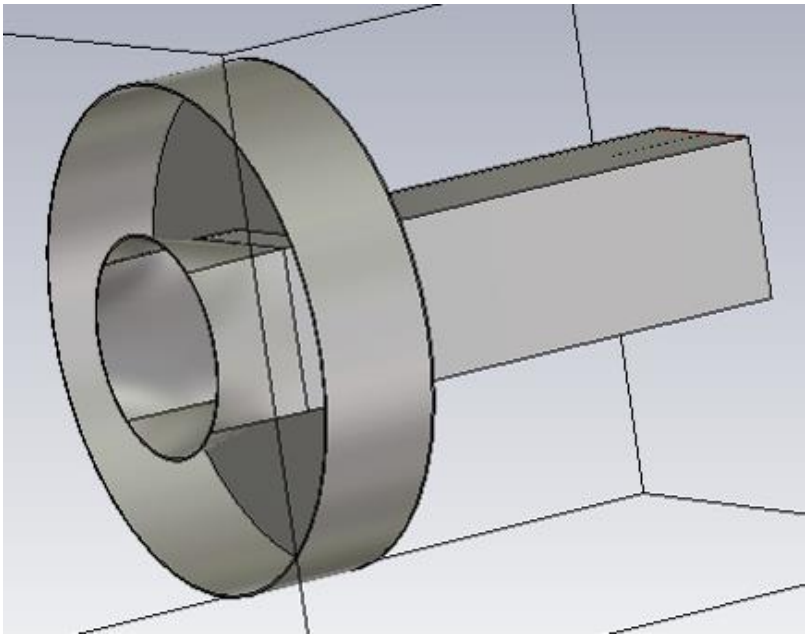


Figure 7-2
Feed with smooth square to round transition (KA1GT)

Simulation results in Figure 7-3 indicate a square feed with a smooth square to round transition has nearly the same pattern as a round feed. Both show the desirable flattening of the radiation pattern. This indicates the square-to-round transition is preserving the dominant TE_{11} mode generated by the round waveguide.

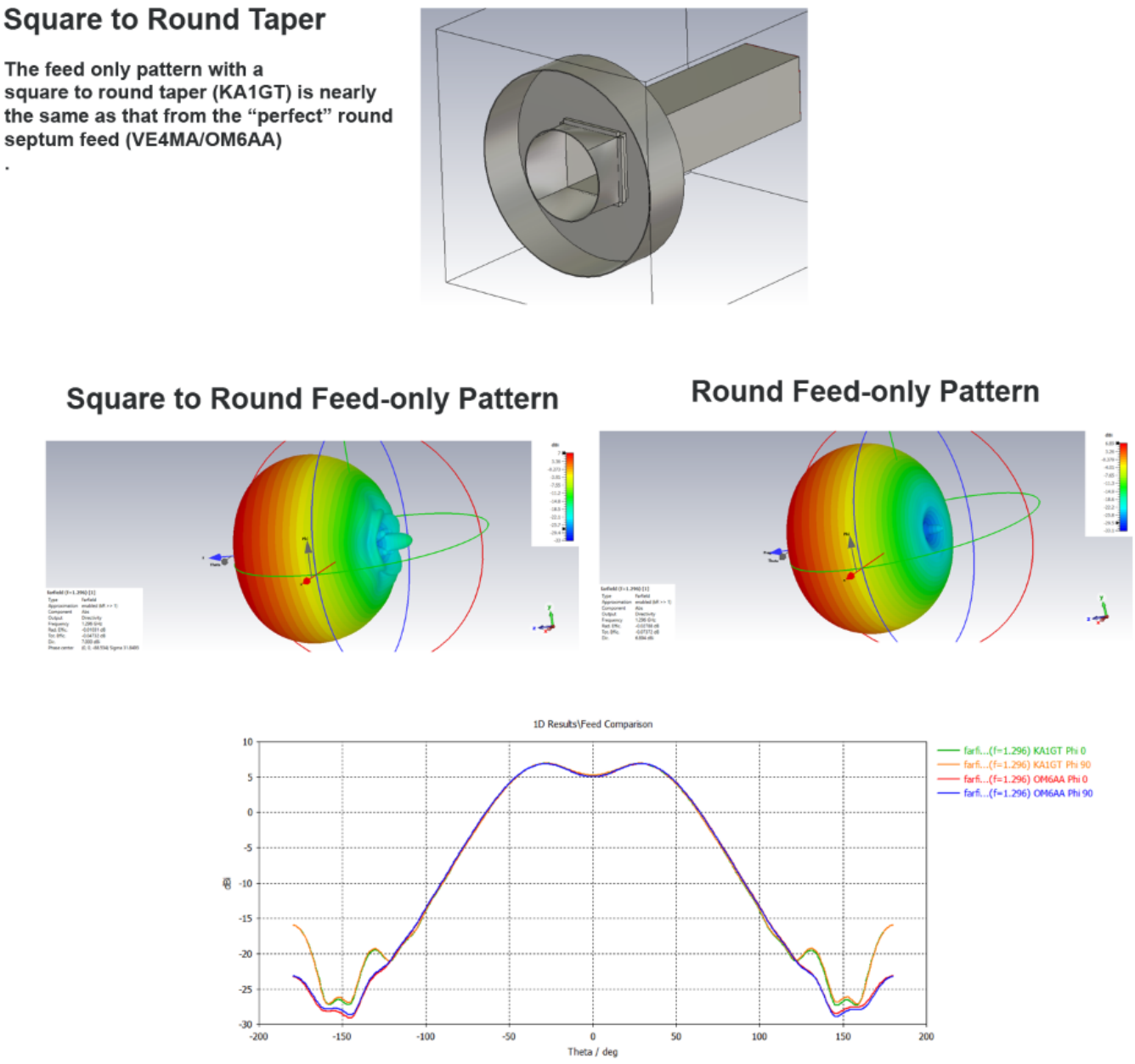

Square to Round Taper
The feed only pattern with a square to round taper (KA1GT) is nearly the same as that from the "perfect" round septum feed (VE4MA/OM6AA)
.
Square to Round Feed-only Pattern
Round Feed-only Pattern
1D Results\Feed Comparison
farfi...(f=1.296) KA1GT Phi 0
farfi...(f=1.296) KA1GT Phi 90
farfi...(f=1.296) OM6AA Phi 0
farfi...(f=1.296) OM6AA Phi 90
dB
Theta / deg

Figure 7-3
Radiation pattern for square to round transition vs round waveguide

8 Optimal feed for 1.9m f/D = 0.35 dish

Extensive simulations were performed to maximize the total system G/Ts and G for the RA3AQ feed, round feed with choke, and square-to-round feed with choke. The RA3AQ septum dimensions remained fixed while we varied the choke and flare to achieve the highest G/Ts and G for the 1.9m, f/D = 0.35 mesh wire dish.

The optimal feed dimensions are shown in Figure 8-1. Figure 8-2 plots G/Ts for the best performing feeds. Figure 8-3 plots G for the best performing feed vs the RA3AQ feed. We observe:

- The overall feed dimensions for the best feed are very similar to those determined by KA1GT based on extensive tuning with sun to cold sky measurements. Noteworthy differences are in the overall feed length (470mm vs 710mm) and the choke setback (30mm vs 15mm).
- The choke setback may be varied to optimize performance for the dish f/D. KA1GT set this to 15mm for an f/D = 0.33 dish. This dimension should be tuned to maximize the sun to cold sky noise ratio.
- The best feed, using a square to round transition, performs better than the round OM6AA feed with optimal dimensions as of 2024. Further optimization of the OM6AA feed was not performed.
- The highest G/Ts was obtained when the dish focal point is 65 mm inside the feed. This same focal point also provides a nearly maximum G.

This section will present noteworthy simulation results and further system optimizations to increase G/Ts. This includes varying feed dimensions, adding a dish collar, and adding an S12 isolation disk. We'll also present experimental results on both the 1.9m dish and a 4.88m f/D = 0.39 dish.

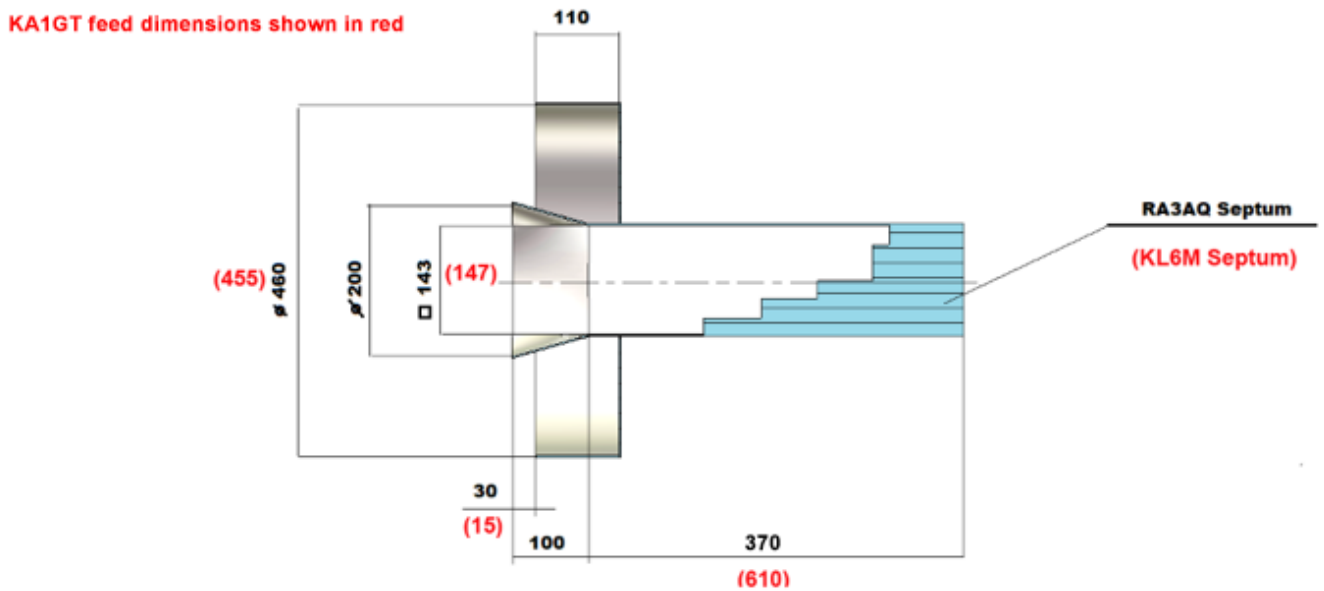


Figure 8-1
Optimal feed for 1.9m, f/D = 0.35 dish

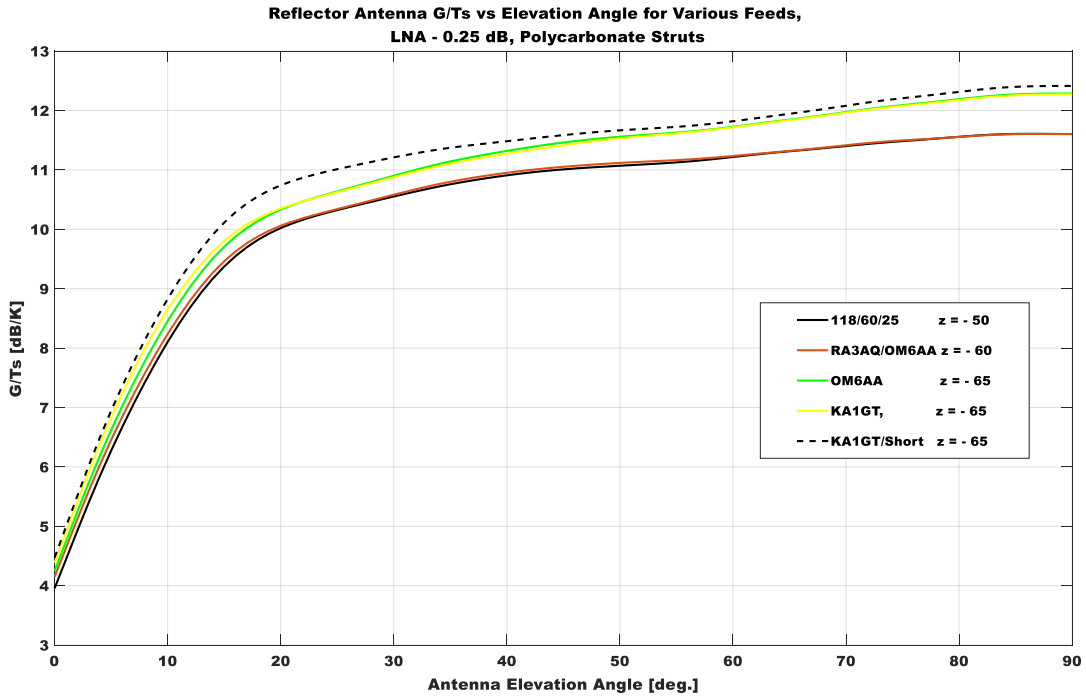

Reflector Antenna G/Ts vs Elevation Angle for Various Feeds,
LNA - 0.25 dB, Polycarbonate Struts
G/Ts [dB/K]
Antenna Elevation Angle [deg.]
118/60/25 z = - 50
RA3AQ/OM6AA z = - 60
OM6AA z = - 65
KA1GT, z = - 65
KA1GT/Short z = - 65

Figure 8-2
G/Ts for best performing feeds

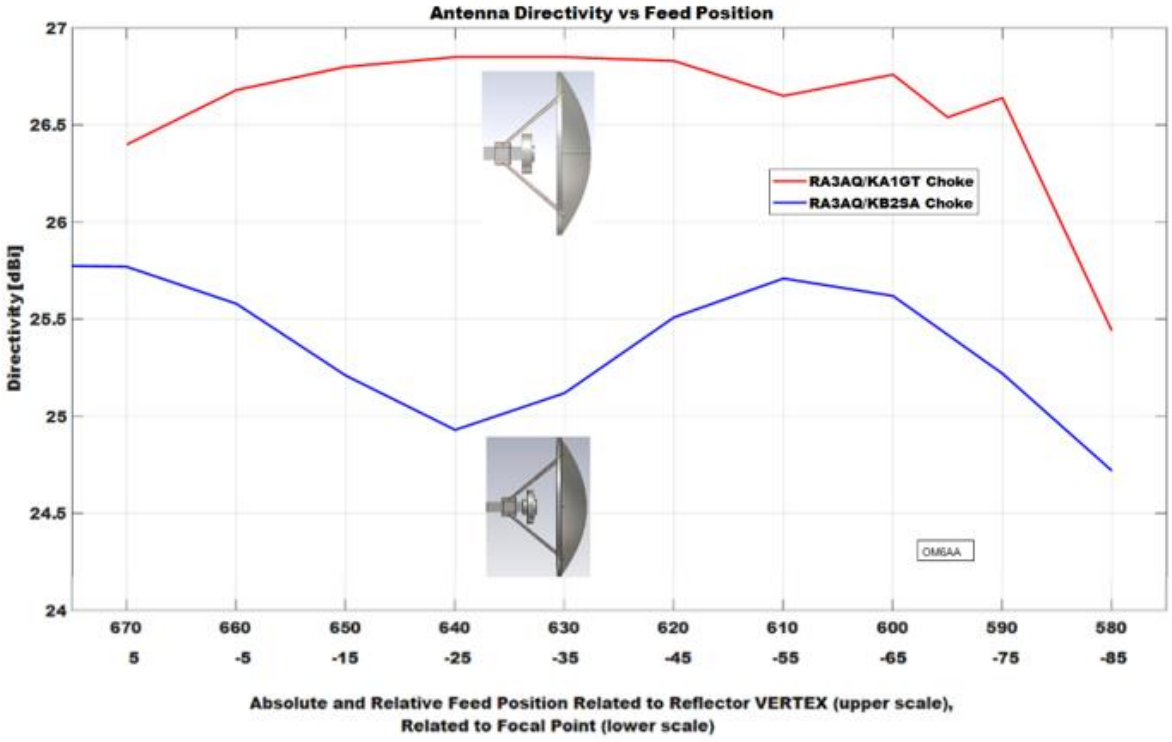

Antenna Directivity vs Feed Position
Directivity [dBi]
RA3AQ/KA1GT Choke
RA3AQ/KB2SA Choke
OM6AA
Absolute and Relative Feed Position Related to Reflector VERTEX (upper scale),
Related to Focal Point (lower scale)

Figure 8-3
G for RA3AQ vs optimal feed

8.1 Radiation pattern vs choke depth

The choke diameter, choke depth and choke offset were varied to maximize G/Ts. *Each simulation required fine-tuning the feed focal point as that varied when other dimensions were changed*. This focal point tuning caused a significant increase in the simulation time. Both I-solver and T-solver settings were used in SIMULIA CST Studio Suite® to help lower the simulation time.

The optimal choke diameter was found to be 460 mm, or approximately twice the wavelength. This is consistent with that predicted by the math[4] and observed experimentally.

Likewise, the optimal choke depth was found to be 110 mm, or approximately half the wavelength. This is also consistent with the math and experimental results.

Figure 8.1-1 illustrates the feed-only simulation results. We observe:

- A choke depth near 100 mm provides the desirable fattened radiation pattern with the lowest sidelobes.
- Other choke depths narrow the pattern and increase sidelobes.
- With a 110 mm choke depth, a 25 mm choke setback provides a slightly wider pattern than a 15 mm setback. This slight variation makes a significant difference in G/Ts.
- *With the optimal choke diameter and depth, the choke setback must be tuned to match the dish f/D.*
- Additional simulation with the RA3AQ feed indicates increased or decreased choke depth does not create the desirable fattened radiation pattern.

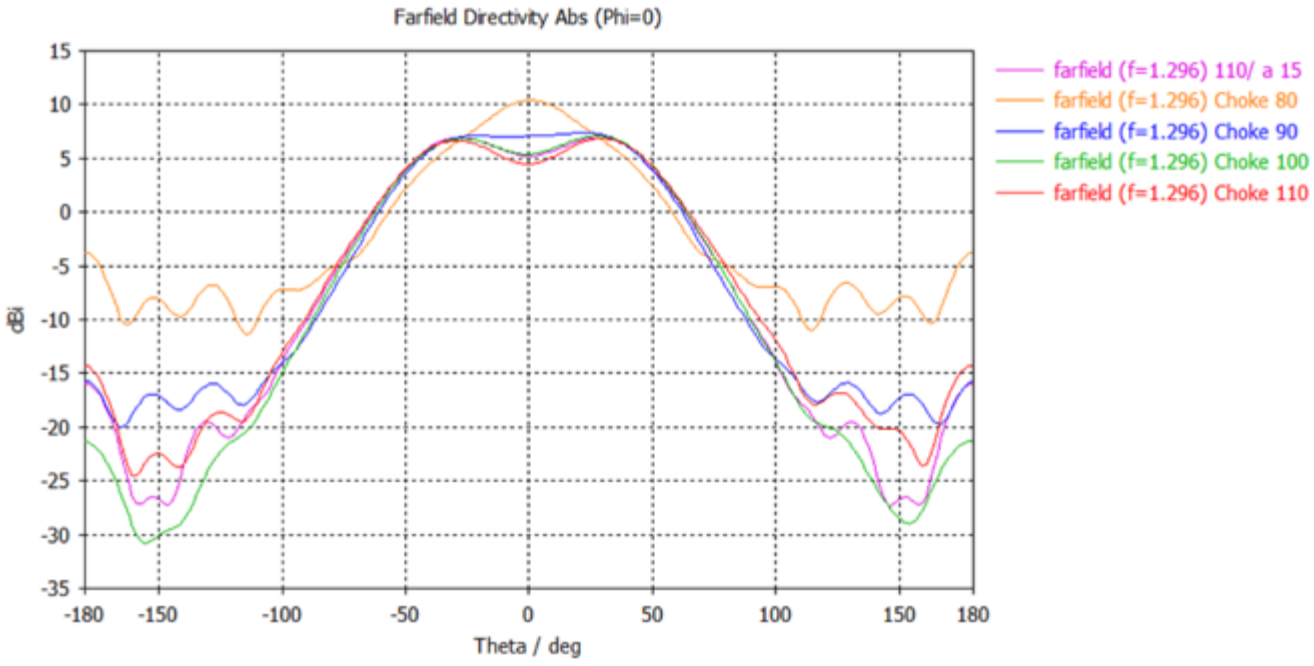


Figure 8.1-1
Square to round feed radiation pattern vs choke depth

8.2 Radiation pattern vs feed length

Figure 8.2-1 illustrates how the feed pattern varies with the feed length. We observe:

- The feed pattern is nearly identical for a 710 mm overall feed length and 470 mm overall feed length.
- The Axial Ratio near boresight is relatively immune to the feed length.

The 470 mm feed length provides a higher G/Ts than a 710 mm feed length. This was illustrated earlier in Figure 8-2. *However, the shorter feed decreases S12 by 2 dB.*

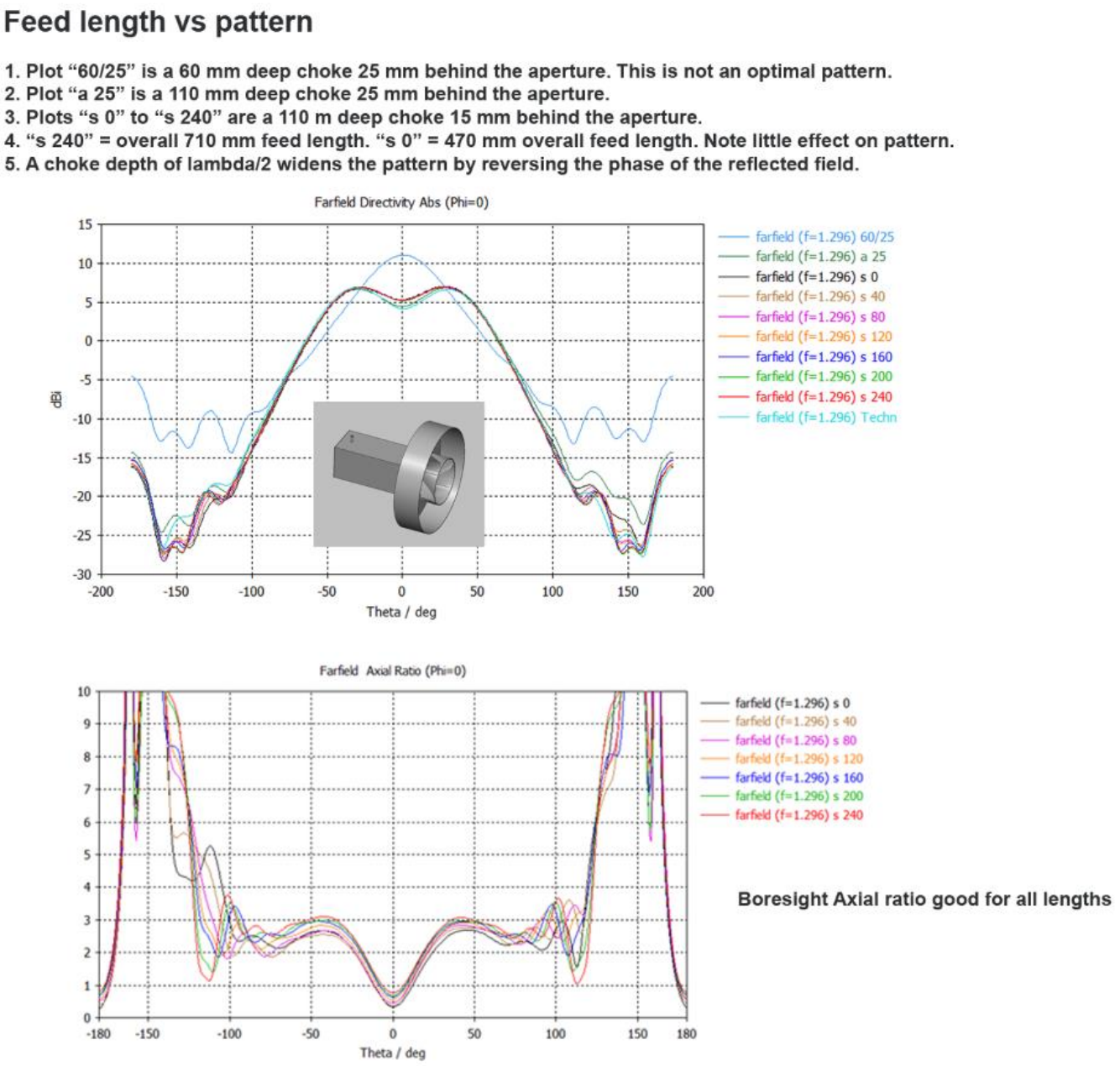

Feed length vs pattern
1. Plot "60/25" is a 60 mm deep choke 25 mm behind the aperture. This is not an optimal pattern.
2. Plot "a 25" is a 110 mm deep choke 25 mm behind the aperture.
3. Plots "s 0" to "s 240" are a 110 m deep choke 15 mm behind the aperture.
4. "s 240" = overall 710 mm feed length. "s 0" = 470 mm overall feed length. Note little effect on pattern.
5. A choke depth of lambda/2 widens the pattern by reversing the phase of the reflected field.
Farfield Directivity Abs (Phi=0)
dBi
Theta / deg
farfield (f=1.296) 60/25
farfield (f=1.296) a 25
farfield (f=1.296) s 0
farfield (f=1.296) s 40
farfield (f=1.296) s 80
farfield (f=1.296) s 120
farfield (f=1.296) s 160
farfield (f=1.296) s 200
farfield (f=1.296) s 240
farfield (f=1.296) Techn
Farfield Axial Ratio (Phi=0)
Theta / deg
farfield (f=1.296) s 0
farfield (f=1.296) s 40
farfield (f=1.296) s 80
farfield (f=1.296) s 120
farfield (f=1.296) s 160
farfield (f=1.296) s 200
farfield (f=1.296) s 240
Boresight Axial ratio good for all lengths

Figure 8.2-1
Square to round feed radiation pattern vs feed length

8.3 Convex choke

Experiments by McInnes and Booker in 1971 indicate a 110° choke flare may provide a “fatter” feed radiation pattern[12]. This fatter pattern may increase G/Ta due to more efficient illumination of the dish. See Figure 8.3-1.

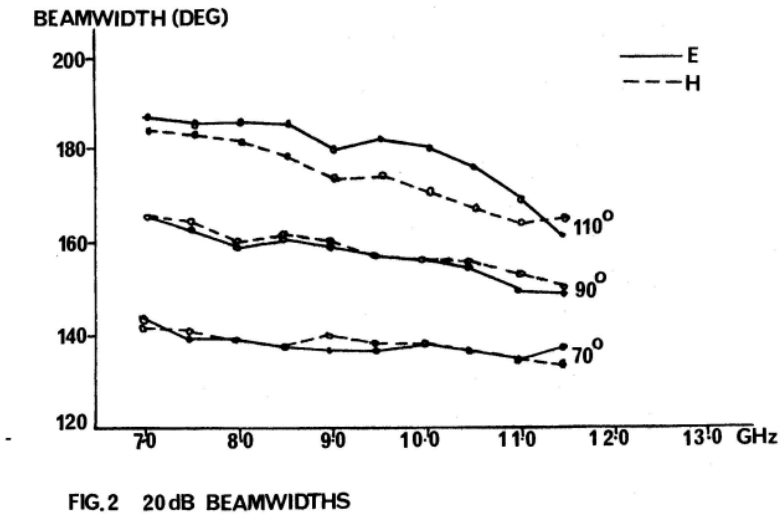


Figure 8.3-1
20 dB beamwidths with 70°, 90° and 110° choke flare

A revisit by Pagana and Massaglia in 1980 indicate a choke flare greater than 90° does not widen the beamwidth.[13] See Figure 8.3-2.

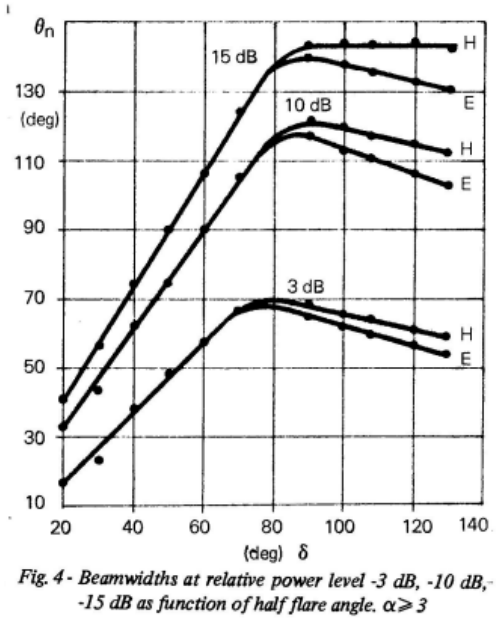


Figure 8.3-2
3 dB, 10 dB and 15 dB beamwidth vs choke flare

Simulations in 2024 confirm the 1980 results using different choke flare angles and choke setbacks. See Figure 8.3-3 when the 460 mm x 110 mm choke, with a 0 mm setback, is flared back 110° and 105°. These feed radiation patterns did not improve G/Ta.

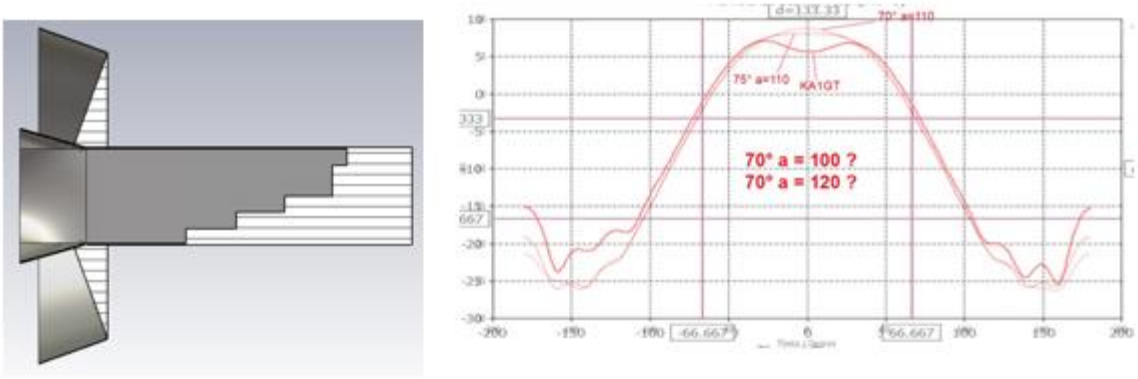


Figure 8.3-3
Radiation pattern for 110° and 105° choke flare vs 90°

8.4 Aperture diameter

It can be shown that the radiation pattern beamwidth for the TE_{11} mode in a hollow pipe increases as the pipe diameter decreases.[14]

Simulation results in Figures 8.4-1 through 8.4-3 indicate similar behavior with the RA3AQ feed.

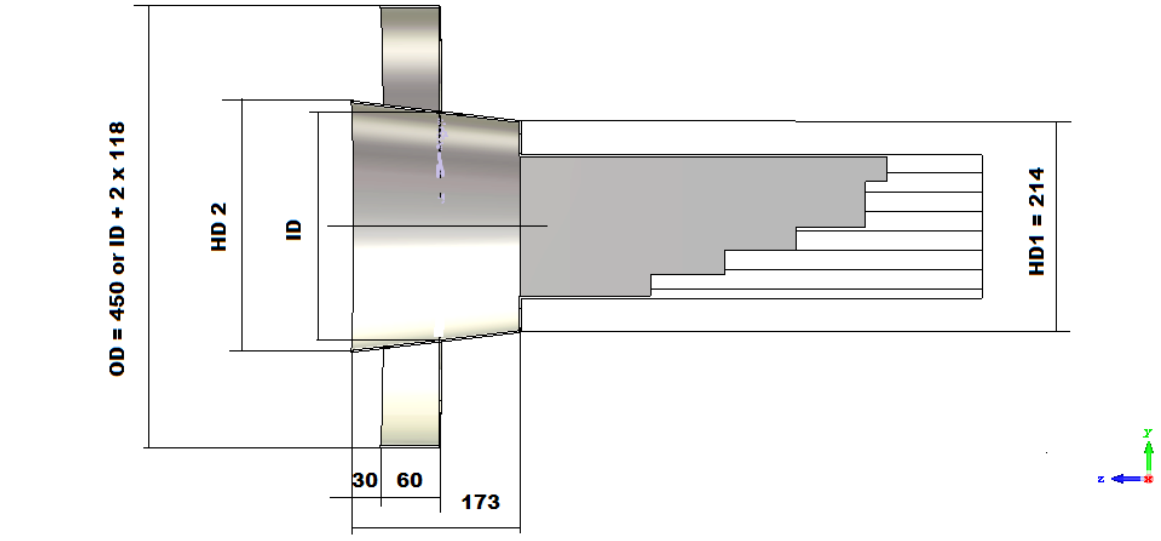


Figure 8.4-1
RA3AQ simulation model for varying aperture diameter

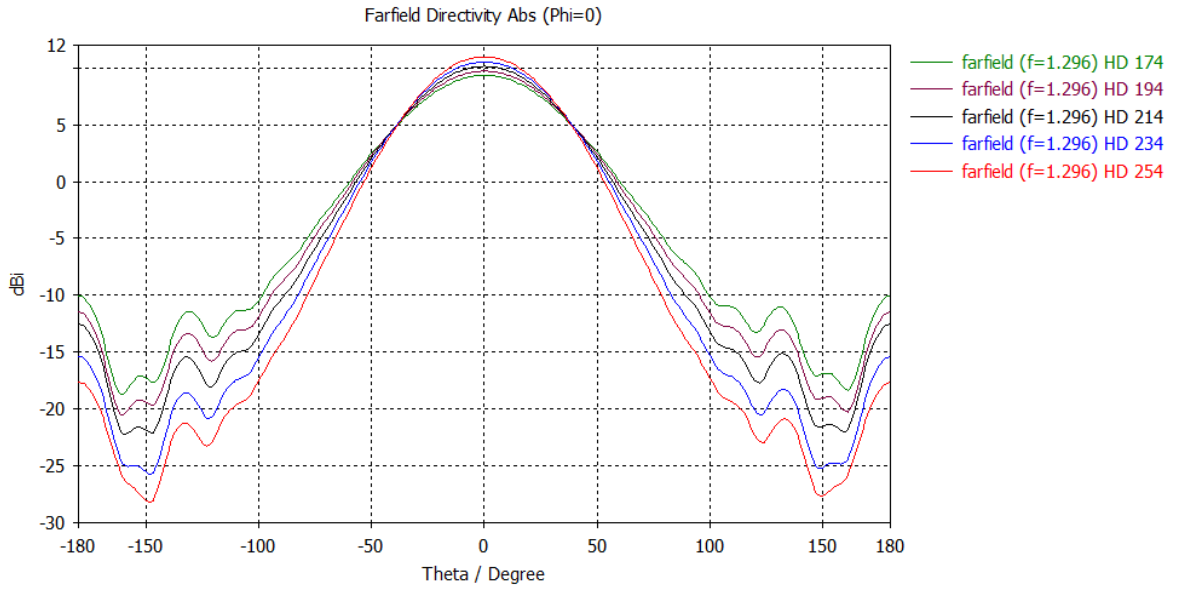


Figure 8.4-2
Feed radiation pattern vs aperture diameter

HD2	Directivity (dB)	Angular width (3dB)	Side lobe level (dB)	Phase center (mm)
174	9.35	62.8	-19.4	0.6
194	9.72	61.0	-21.2	-1.56
214	10.14	58.6	-22.7	-3.14
234	10.51	56.9	-25.9	-7.82
254	10.97	54.1	-28.6	-9.99

Figure 8.4-3
Feed radiation measurements vs aperture diameter

When the dish is added, the best G/Ta is obtained with a 194 mm aperture diameter as illustrated in Figure 8.4-4.

Figure 8.4-5 illustrates the effects of the choke setback on G/Ta at the optimal aperture diameter.

These simulations on the RA3AQ feed indicate G/Ta can be optimized by varying both the aperture diameter and choke setback.

Given these results for the RA3AQ feed, there was interest in determining if decreasing the 200 mm aperture diameter for the optimal feed (i.e., a wider feed pattern) may further increase G/Ta. Figure 8.4-6 illustrates the simulation results for aperture diameters from 144 mm to 200 mm using a deeper f/D = 0.3 dish. Very little change was seen in G/Ta and the system could not perform as well as the optimal f/D = 0.35 system.

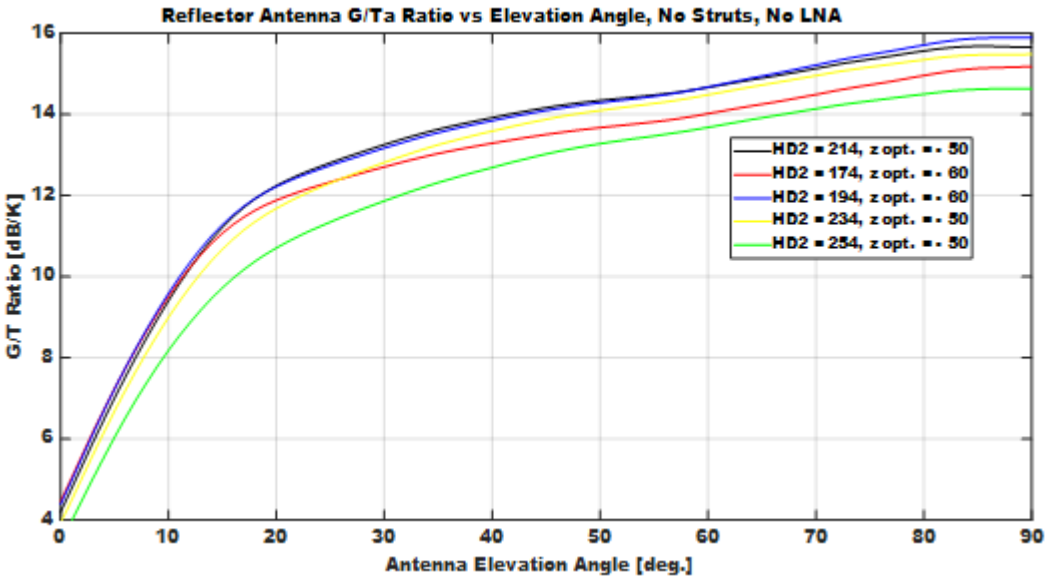

Reflector Antenna G/Ta Ratio vs Elevation Angle, No Struts, No LNA
G/T Ratio [dB/K]
Antenna Elevation Angle [deg.]
HD2 = 214, z opt. = - 50
HD2 = 174, z opt. = - 60
HD2 = 194, z opt. = - 60
HD2 = 234, z opt. = - 50
HD2 = 254, z opt. = - 50

Figure 8.4-4
G/Ta vs aperture diameter at optimal focal point

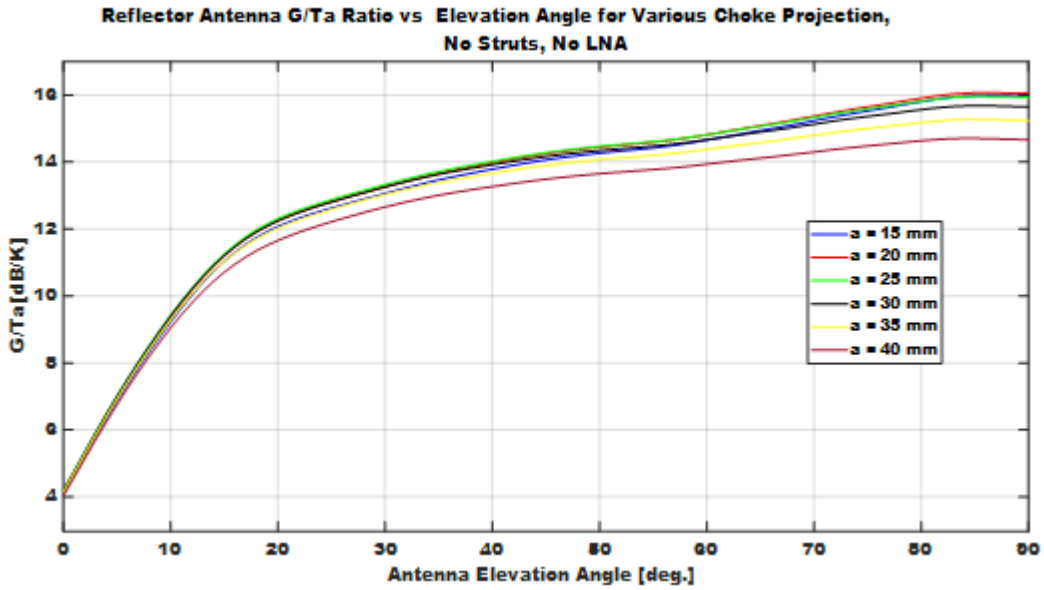

Reflector Antenna G/Ta Ratio vs Elevation Angle for Various Choke Projection,
No Struts, No LNA
G/Ta [dB/K]
Antenna Elevation Angle [deg.]
a = 15 mm
a = 20 mm
a = 25 mm
a = 30 mm
a = 35 mm
a = 40 mm

Figure 8.4-5
G/Ta vs choke setback at optimal aperture diameter

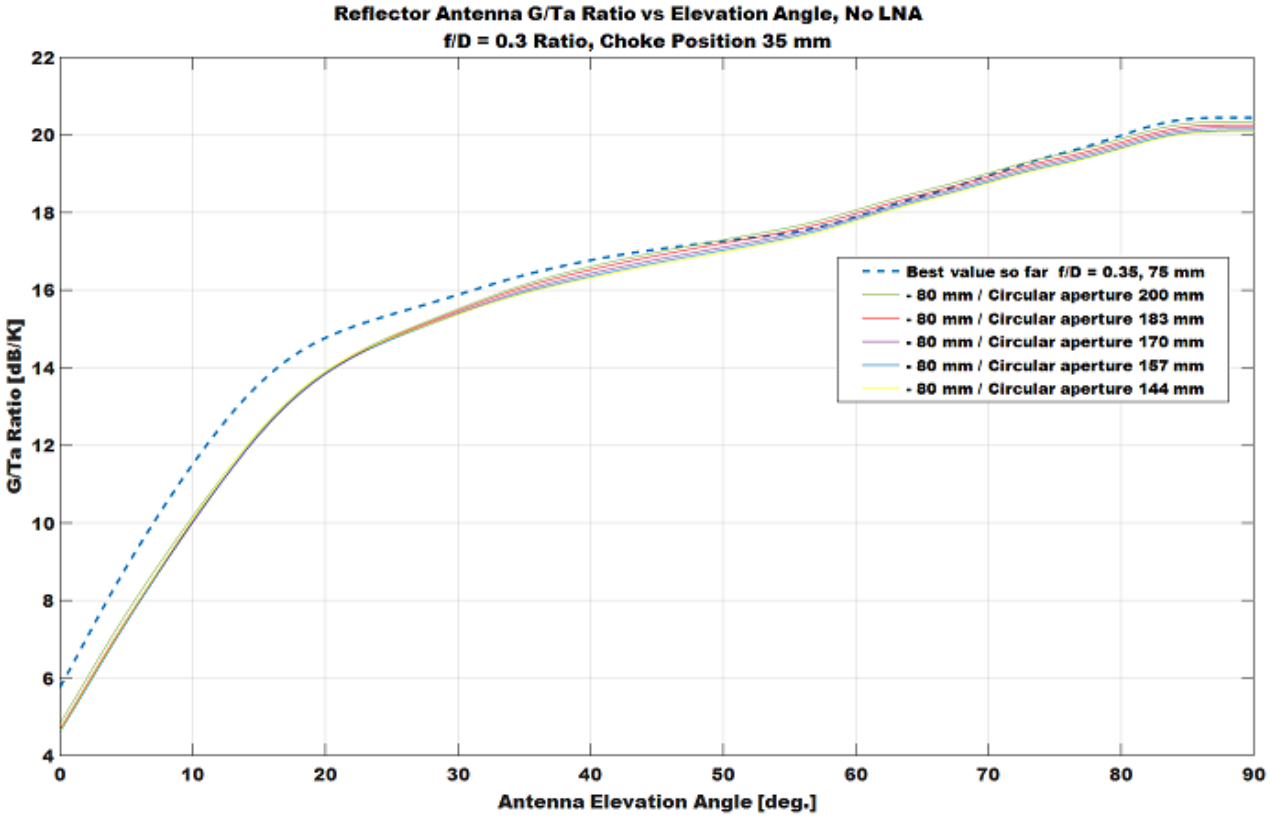

Reflector Antenna G/Ta Ratio vs Elevation Angle, No LNA
f/D = 0.3 Ratio, Choke Position 35 mm
G/Ta Ratio [dB/K]
Antenna Elevation Angle [deg.]
Best value so far f/D = 0.35, 75 mm
- 80 mm / Circular aperture 200 mm
- 80 mm / Circular aperture 183 mm
- 80 mm / Circular aperture 170 mm
- 80 mm / Circular aperture 157 mm
- 80 mm / Circular aperture 144 mm

Figure 8.4-6
G/Ta vs aperture diameter for f/D = 0.30

8.5 Other f/D

Figure 8.4-6 illustrates lower G/Ta performance for an f/D = 0.30 dish with various aperture diameters at an optimal -80 mm focal point and optimal 35 mm setback for the 460 mm x 110 mm choke.

Figures 8.5-1 and 8.5-2 illustrate G/Ta performance for the 200 mm aperture diameter and 460 mm x 110 mm choke with the choke setback and focal point varied for highest G/Ta. These simulation results indicate a deeper f/D = 0.33 dish has a slight (< 0.5 dB) improvement at higher elevation angles. A shallower f/D = .36 dish did not show improvement.

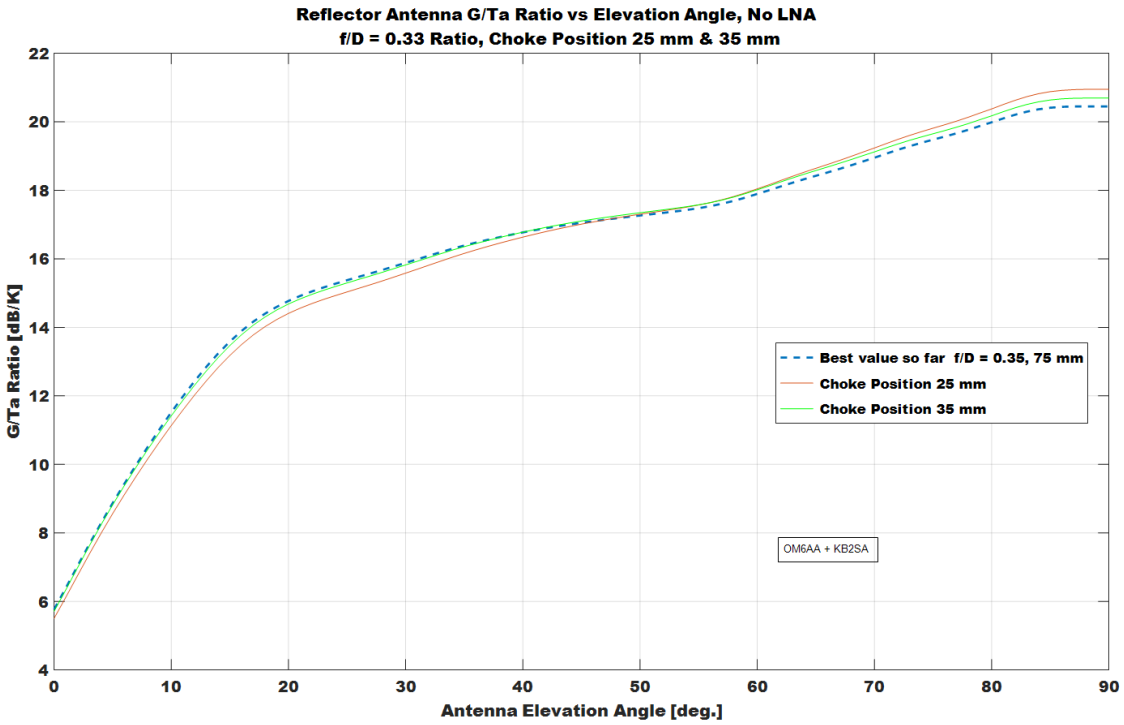

Reflector Antenna G/Ta Ratio vs Elevation Angle, No LNA
f/D = 0.33 Ratio, Choke Position 25 mm & 35 mm
G/Ta Ratio [dB/K]
Antenna Elevation Angle [deg.]
Best value so far f/D = 0.35, 75 mm
Choke Position 25 mm
Choke Position 35 mm
OM6AA + KB2SA

Figure 8.5-1
G/Ta vs choke setback at optimal focus for f/D = 0.33

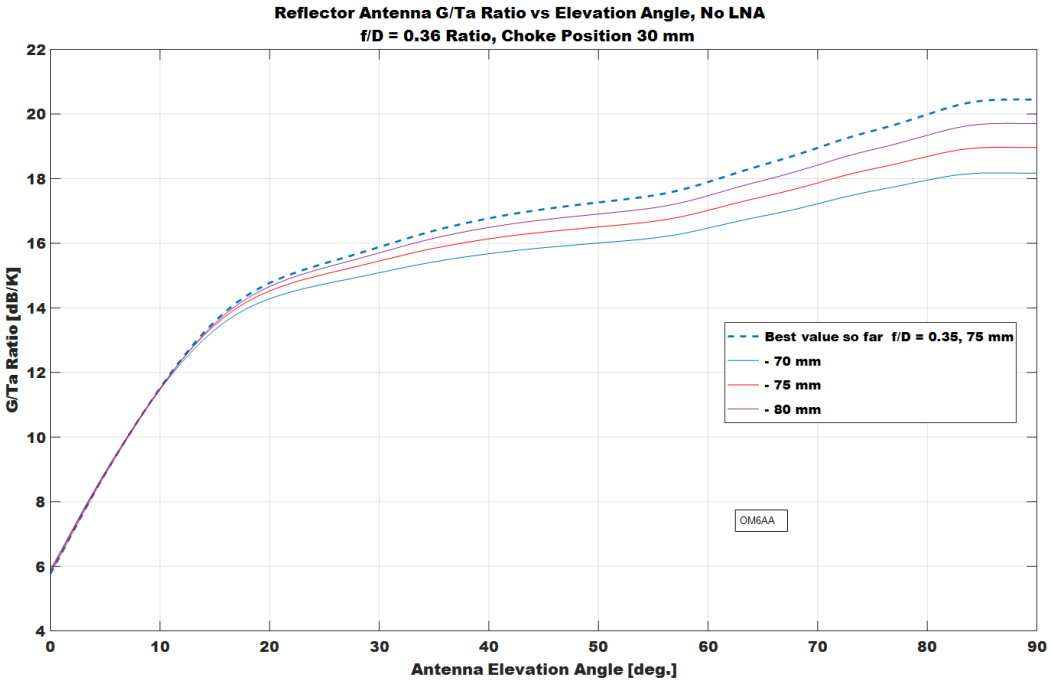

Reflector Antenna G/Ta Ratio vs Elevation Angle, No LNA
f/D = 0.36 Ratio, Choke Position 30 mm
G/Ta Ratio [dB/K]
Antenna Elevation Angle [deg.]
Best value so far f/D = 0.35, 75 mm
- 70 mm
- 75 mm
- 80 mm
OM6AA

Figure 8.5-2
G/Ta vs focus at optimal choke setback for f/D = 0.36

8.6 S12 and its effect on G/Ts

When the square to round transition is added to the feed, the measured isolation between the Tx and Rx ports (S12) is reduced from 20 dB (RA3AQ feed) to only 14 dB when the feed is installed on the dish. The abrupt square to round transition in the RA3AQ feed appears to improve S12. This behavior was not analyzed further.

If S12 is relatively low, any noise on the Tx port will be added to the Rx port. This will degrade G/Ts.

Figure 8.6-1 illustrates S12 simulations. At 1296 MHz near the optimal focal point, S12 is approximately 16 dB vs 14 dB measured.

If we assume:

- 85° F ambient (300K)
- LNA NF = 0.25 dB
- S12 = 14 dB
- Relay + connector loss = 0.1 dB

We estimate:

- RX noise from TX port = 300 / 10^(14/10) = 12K
- Equivalent LNA noise = 300 * (10^((0.25+0.1)/10) – 1) = 25K
- Antenna noise @ 30° elevation = 12K
- Total system noise = 12K + 25K + 12K = 49K

If we remove the 12K Tx port noise that's added to the Rx port noise, we estimate a 10 * LOG [49/(49-12)] = 1.2 dB increase in receive sensitivity.

The 50-ohm thermal noise may be removed from the Tx port using a relay. Alternatively, RA3AQ suggested placing a small disk inside the round aperture.

Figure 8.6-2 indicates a 50 mm disk placed 45 mm inside the aperture reduces cold sky noise by nearly 1 dB. This disk size and placement was determined by simulation and then optimized with actual measurements of cold sky noise.

Simulation results in Figures 8.6-3 and 8.6-4 indicate S12 has increased from 14 dB to over 30 dB with no effect on G/Ts.

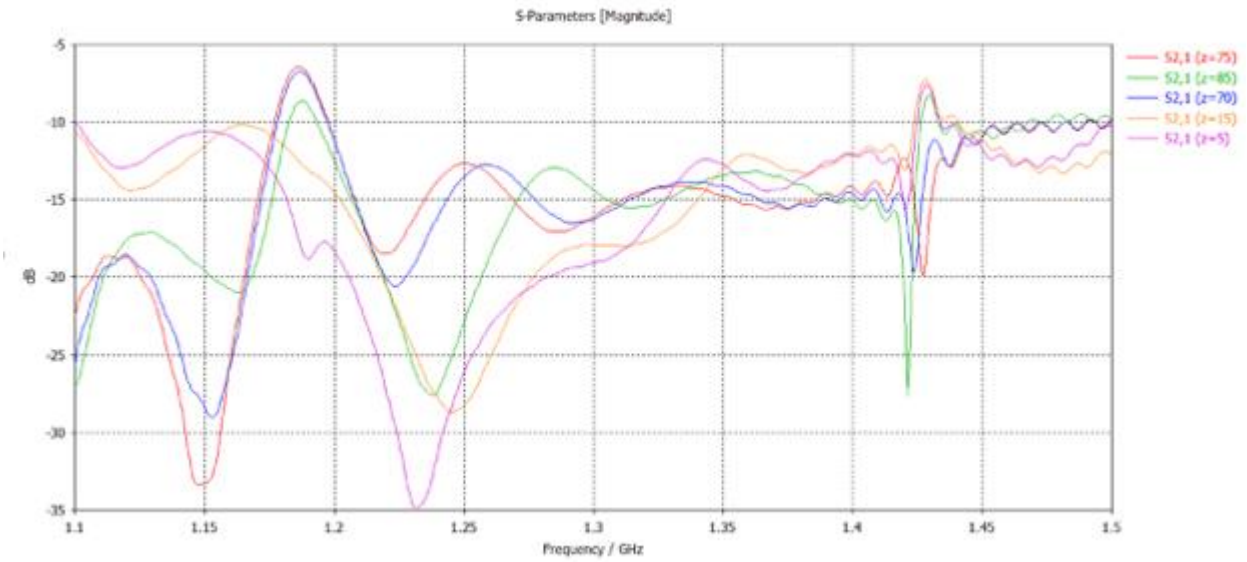


Figure 8.6-1
S12 vs frequency and focal point

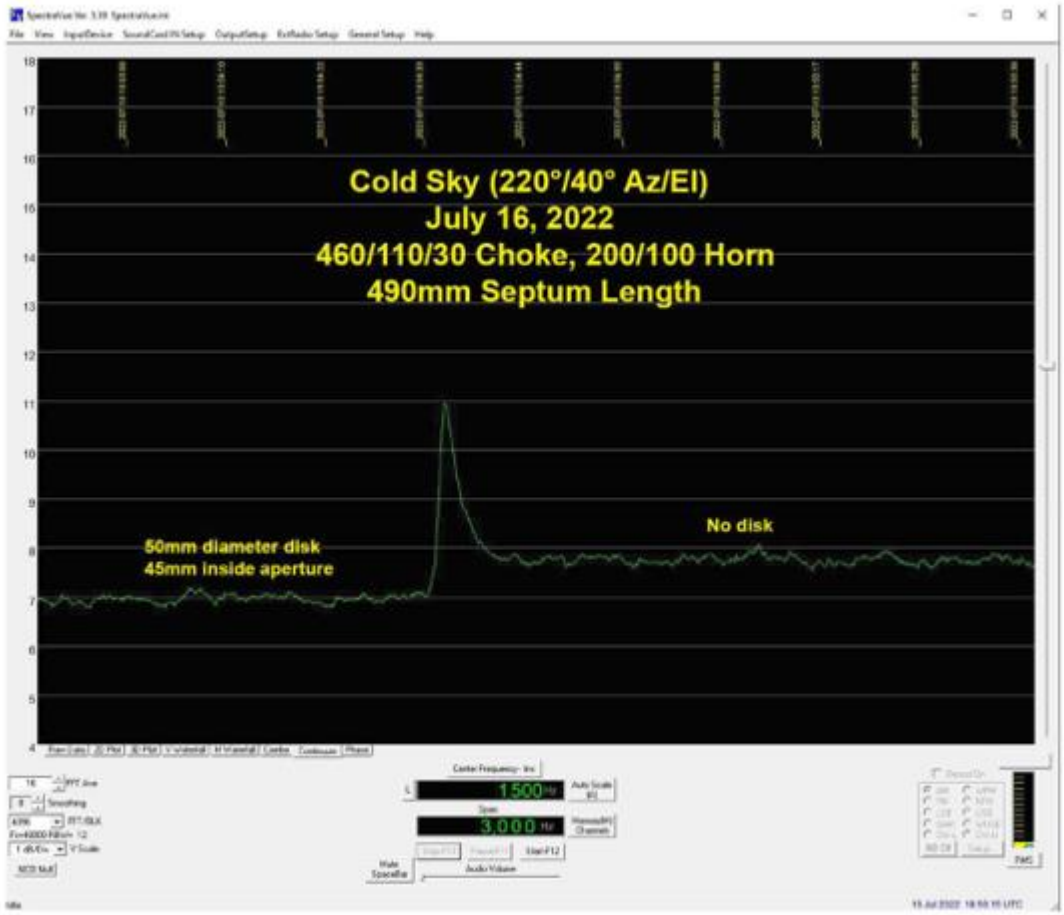
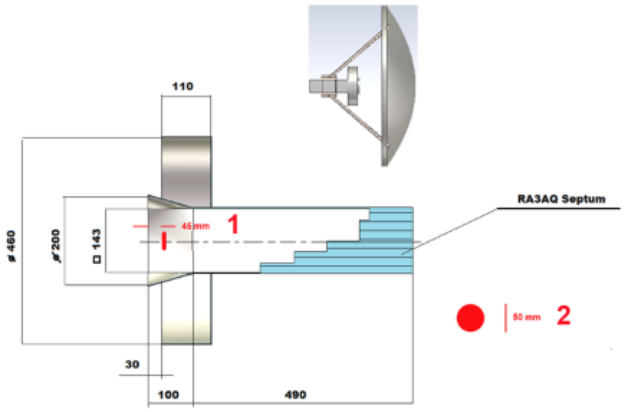


Figure 8.6-2
Cold sky noise with and without S12 disk

Simulations varied the disk diameter and placement to help characterize the behavior.

S12?

Z	1	2
65	45	50
65	45	45
65	45	55
65	40	45
65	40	50
65	40	55
65	50	45
65	50	50
65	50	55



Simulation found the disk placement and diameter did not change the overall G/Ts.

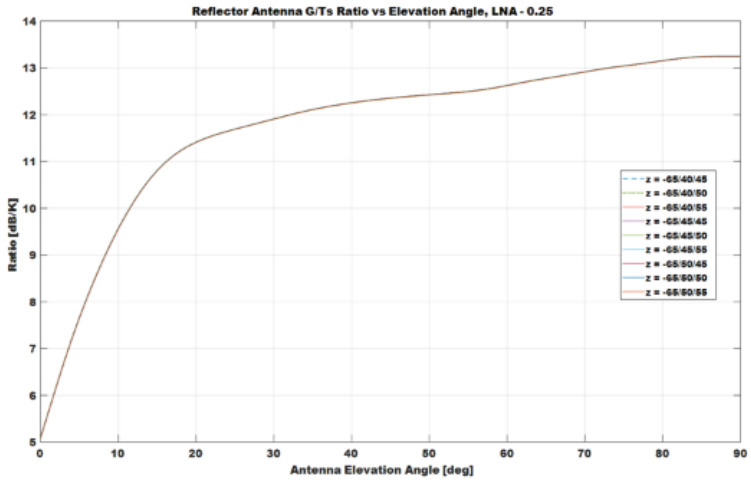


Figure 8.6-3
S12 simulation model and G/Ts vs disk placement/diameter

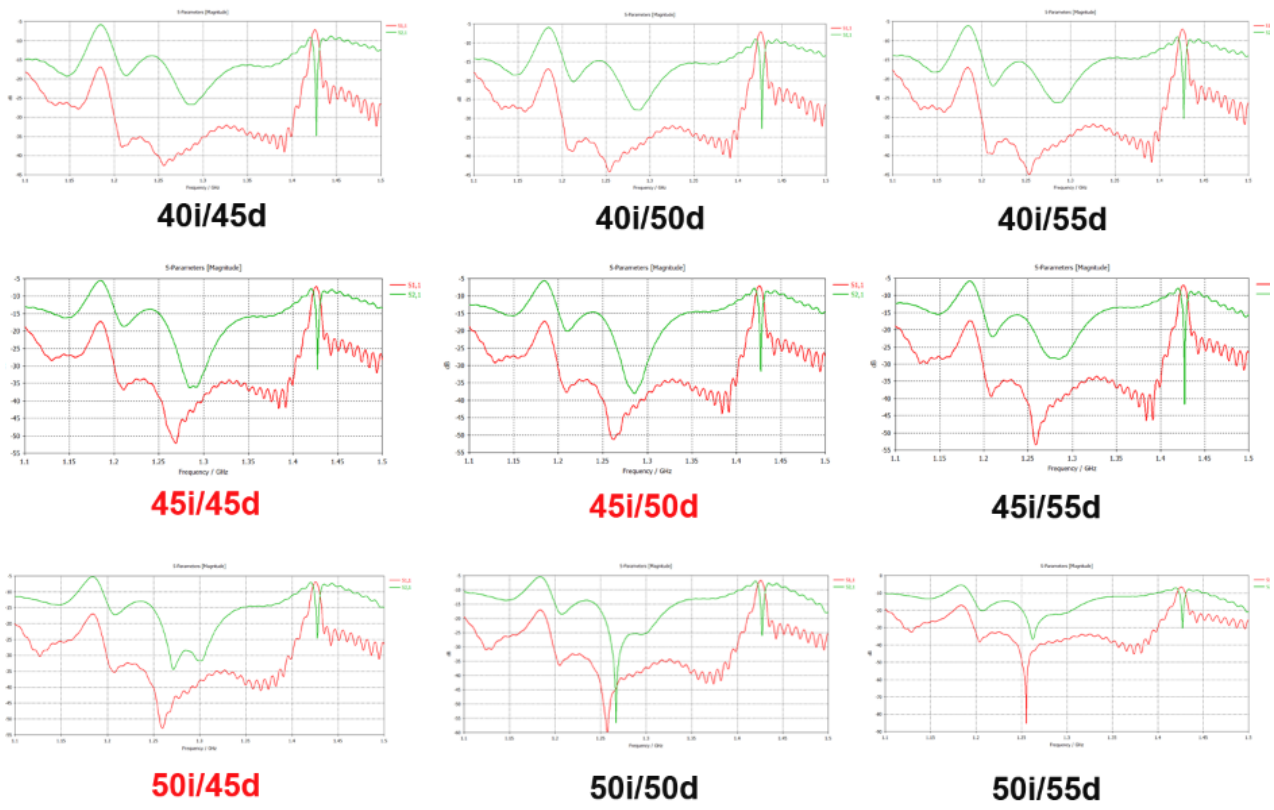


Figure 8.6-4
Simulated S12 vs disk placement/diameter

8.7 Dish collar ring

During simulation of the 1.9m dish and feed system, two optimal focal points were obtained. This hints that the system may be operating as a Short Backfire Antenna (SBF).[15]

Experimental studies have shown an SBF performance improvement with an added λ/4 dish collar ring perpendicular to the wavefront.

Simulation results in Figure 8.7-1 show a 1 dB minimum increase in G/Ta with the added dish collar ring. Experimental sun to cold sky measurements indicate a minimum sun to cold sky improvement of 0.5 dB.

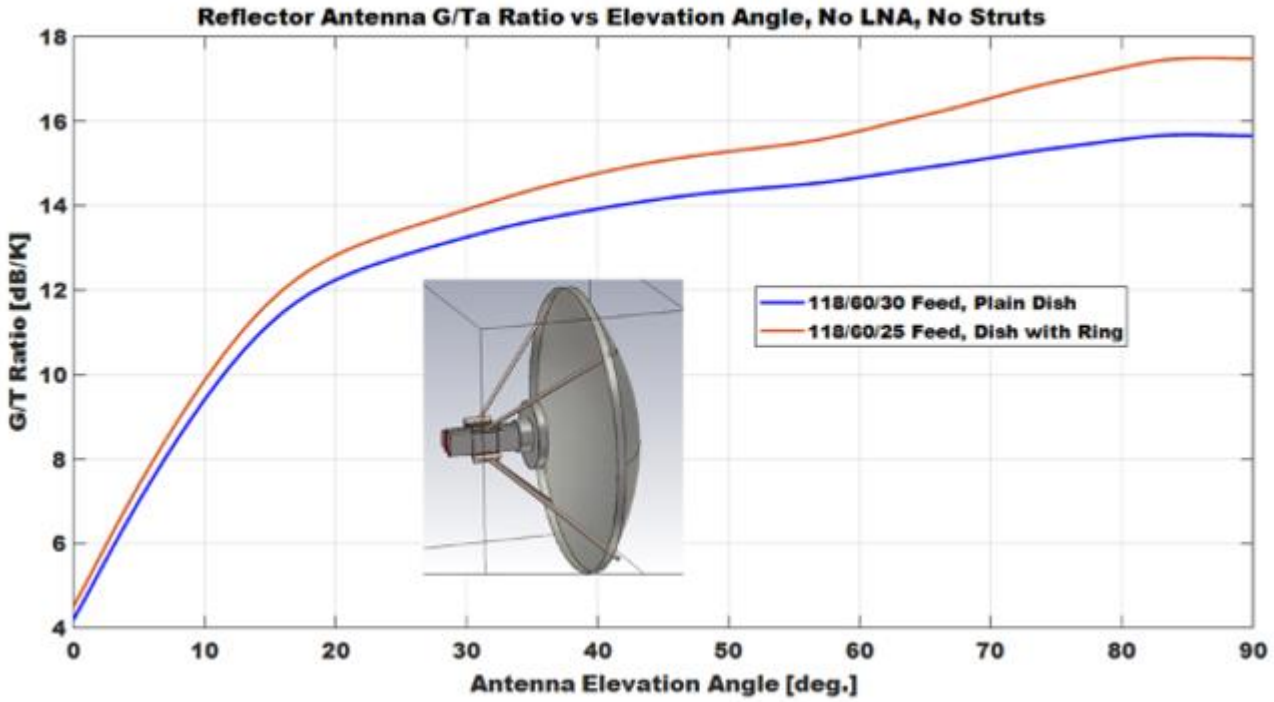

Reflector Antenna G/Ta Ratio vs Elevation Angle, No LNA, No Struts
G/T Ratio [dB/K]
Antenna Elevation Angle [deg.]
118/60/30 Feed, Plain Dish
118/60/25 Feed, Dish with Ring

Figure 8.7-1
G/Ta with dish vs dish and collar ring

9 Cold sky to sun measurements

Tuning the feed within the dish may be done by pointing the dish at a point in the sky having the lowest noise and then pointing at the sun. The highest G/Ts is obtained with the maximum difference between cold sky noise and sun noise. Maximizing on just sun (G) may not provide the lowest antenna noise (Ta). See Figure 9-1 for the optimal feed in a 1.9m f/D = 0.35 dish with Solar Flux unit (SFU) = 166.

When tuning:

- Set the feed to the dimensions shown in Figure 8-1 with the focal point for the dish placed 65 mm inside the round aperture.
- First move the feed in and out in 10 mm steps to maximize cold sky to sun.
- Next move the choke setback in and out in 5 mm steps to maximize cold sky to sun.
- Repeat the feed and choke tuning multiple times to ensure the highest cold sky to sun difference.

When tuning the feed and choke, note:

- The point in the sky having the lowest noise should be above 60° elevation and free of any path obstacles. Even distant trees can cause noise that may interfere with the measurement. In San Diego CA, cold sky is typically near 80° azimuth and 70° elevation.

- Sun should be above 40° elevation to minimize ground noise contribution.
- Sun noise can vary 1 dB or more during the measurement intervals.
- Nearby activity (e.g., lawn mowers, leaf blowers) can increase cold sky noise.

If noise is being measured by observing the audio output of a receiver, note:

- The receiver AGC, NR and NB should be off with the LNA installed.
- Receiver bandwidth set for normal operation (e.g., 3000 hz).
- The receiver should operate in its linear region. This will likely require lowering the RF gain when pointing at the sun until no saturation is seen or heard in the audio output (e.g., by observing the digital sound card output on the SpectraVue™ Continuum display or similar).
- Ensure cold sky noise is still present at the audio output. This may require increasing the RF gain.

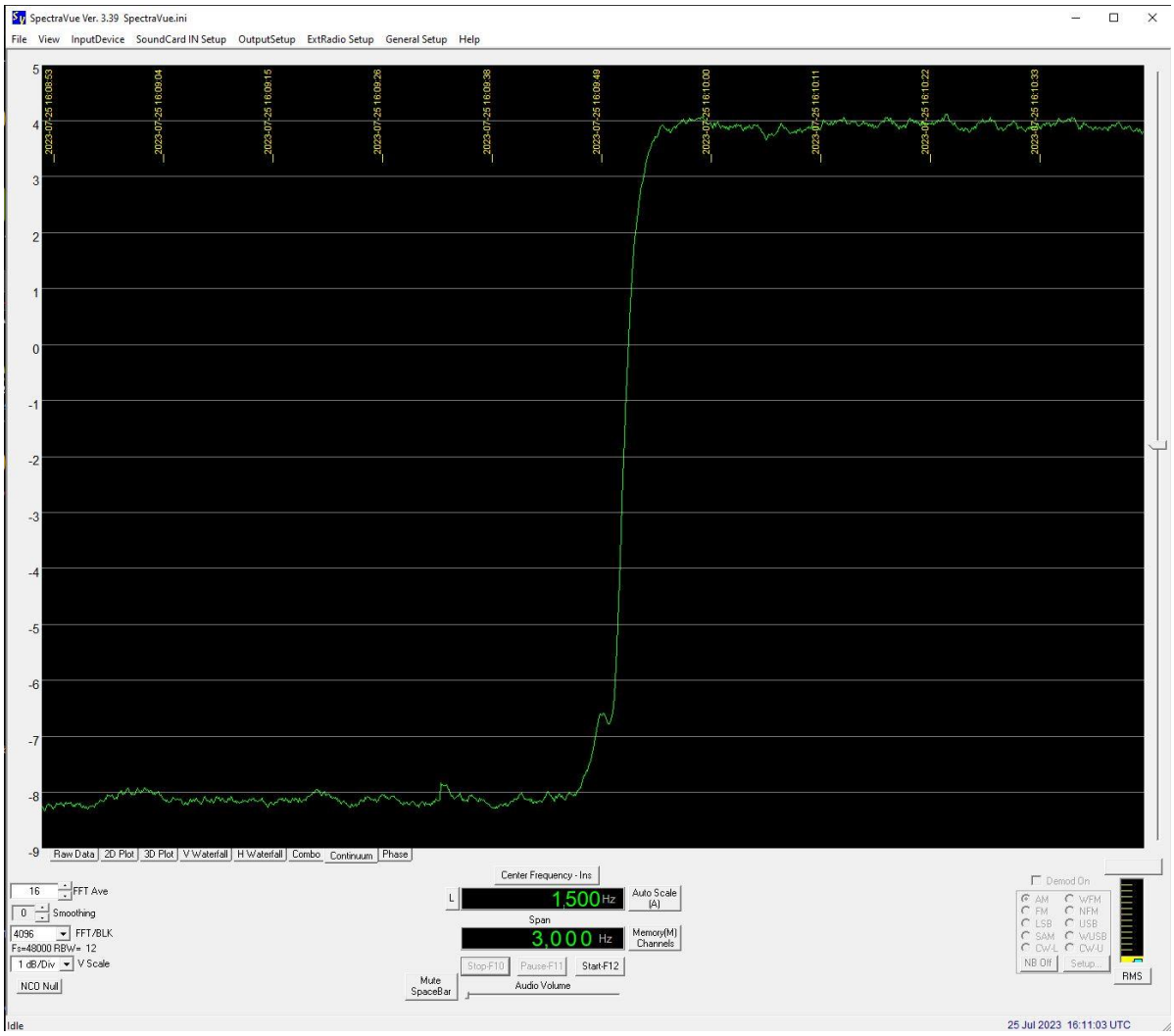


Figure 9-1
12 dB cold sky to sun noise using SpectraVue™ with sun SFU = 169

Figure 9-2 plots cold sky to sun noise as a function of sun SFU using the system illustrated in this paper (i.e., 1.9m f/D = 0.35 wire mesh dish, collar ring, fiberglass struts, 0.25 dB NF LNA and S12 disk). These measurements were taken during 2023 and 2024.

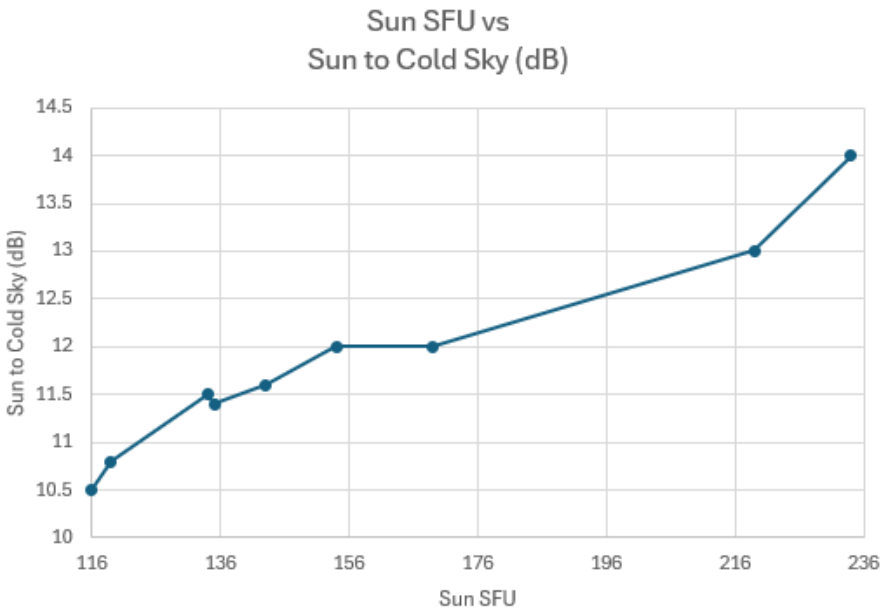


Figure 9-2
Sun to cold sky noise vs SFU (dB) for subject system

10 Optimal 1.9m feed on 4.88m dish

KD5FZX expertly constructed the optimal feed and installed it on a 4.88m f/D = 0.39 dish. We observe:

- The theoretical difference between 1.9m and 4.88m is approximately 8 dB.
- A 7 to 8 dB difference is measured on both receive and transmit with hundreds of EME QSOs and echo tests.
- Approximately 1 dB loss is suspected due to the non-optimal f/D = 0.39.

Figure 10-1
KD5FZX solid 4.88m dish with optimal feed

Figure 10-2
Polycarbonate color for tunable S12 disk and birds/insects

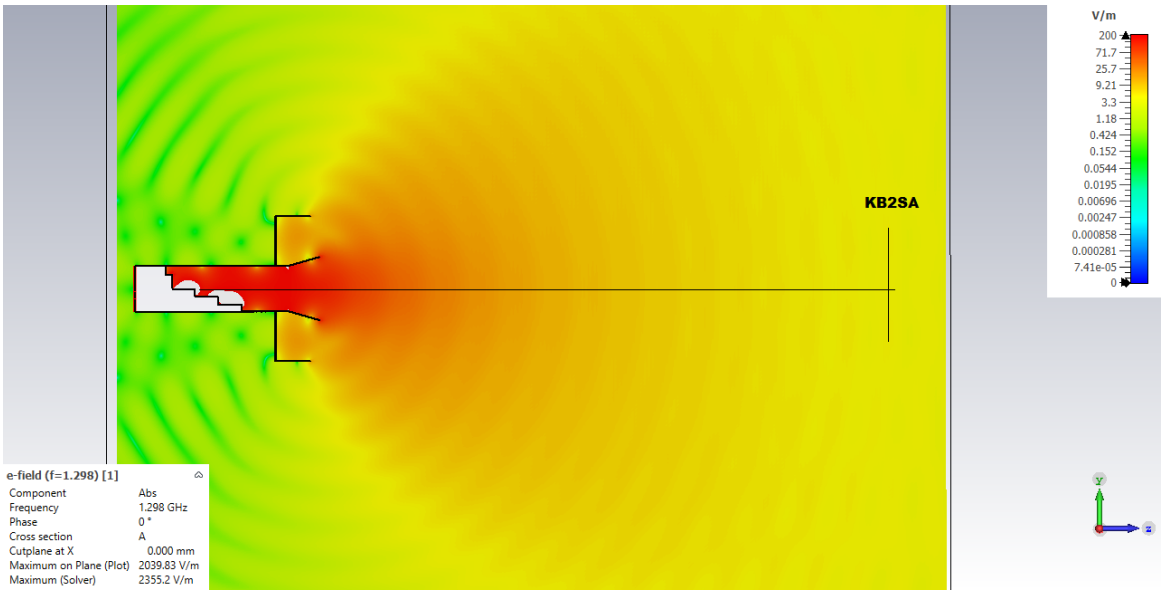


Figure 10-3
Radiation pattern of optimal feed relatively uniform in near, fresnel and far field

11 Noteworthy 23cm EME QSOs with 1.9m

Measurable noteworthy 23cm EME QSOs with the 1.9m system illustrated in this paper include:

- PA3DZL with 23-element yagi (Q65-120D)
- BH1TSI with 36-element yagi (Q65-120D)
- ZC4RH with 67-element yagi (Q65-120D)
- DK0TE with 70-element yagi (Q65-60C and Q65-30B)
- ZL1NJT with 1.8m folding dish through trees (Q65-60C)
- KA1GT with 3.1m dish and 5 watts (Q65-60C and Q65-120D)
- WAS #24. Thank you Peter KA6U and Gene KB7Q!
- 2,895+ QSOs on LoTW
- ARRL International EME Contest, SO-1.2G
    - 2023 #11/60
    - 2022 #13/43
    - 2021 #16/51

Figure 11-1
Mug celebrating “world record” QSO with PA3DZL

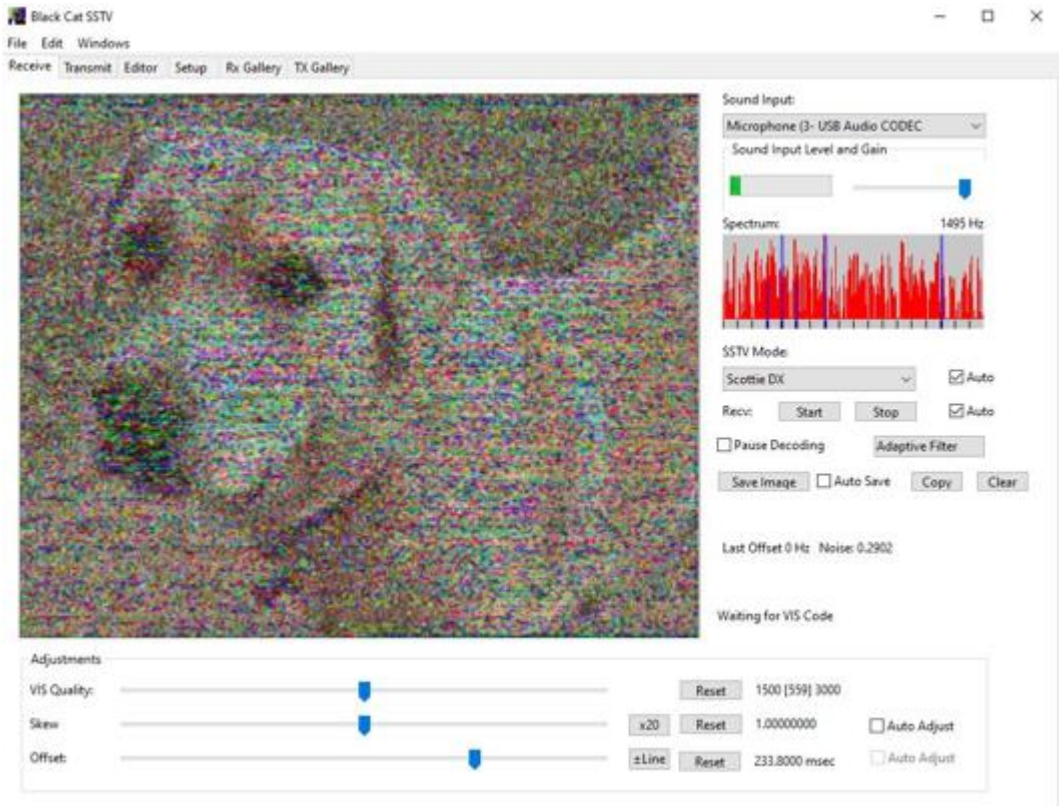


Figure 11-2
Scottie DX EME SSTV received from KD5FZX

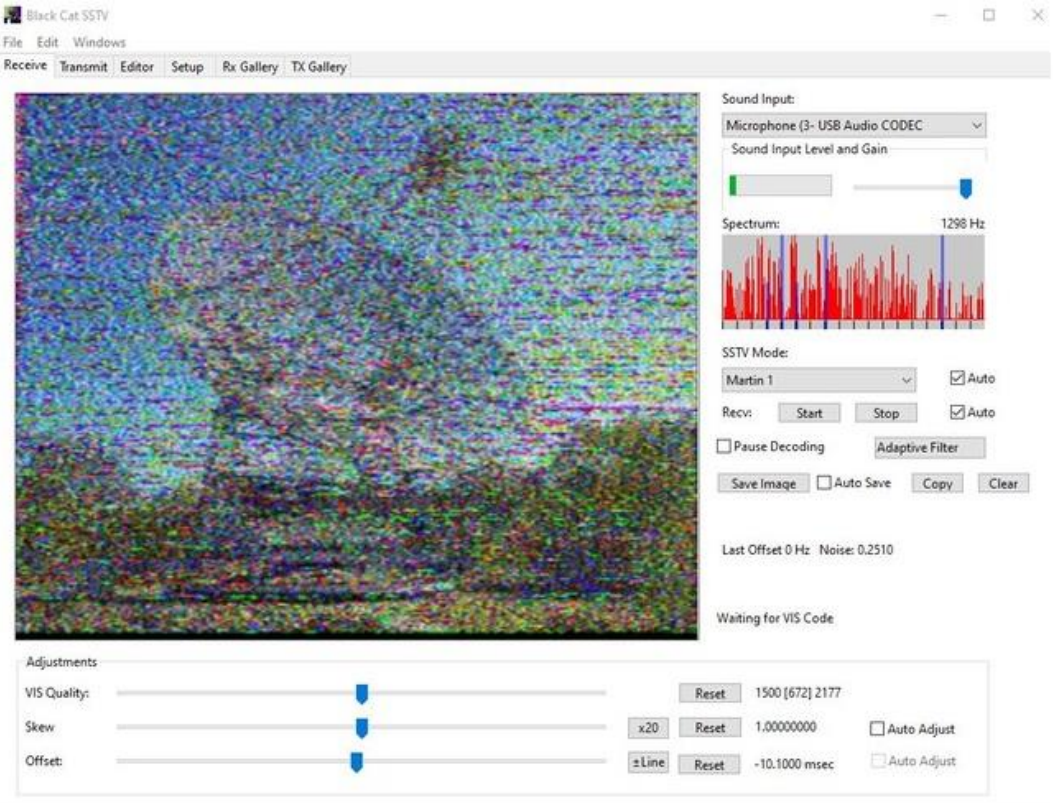


Figure 11-3
Martin 1 EME SSTV received from K0PRT

12 What's next?

We're currently analyzing the performance of a Cassegrain antenna[16] for 23cm EME. Preliminary analysis indicates "acceptable" G/Ts performance with existing feed designs. Excellent performance may require a new feed design with a narrow radiation pattern.

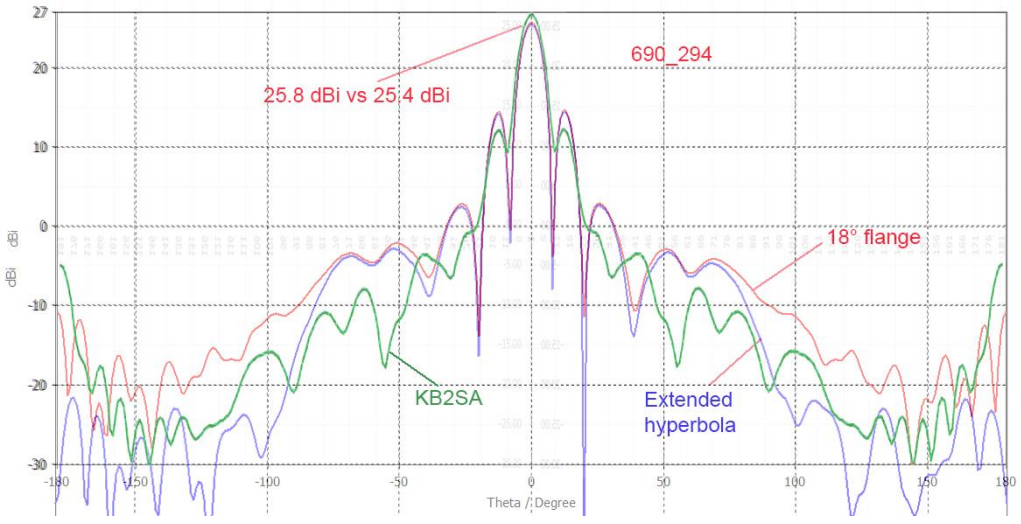


Figure 12-1
Radiation pattern for 1.9m Cassegrain antenna vs optimal feed

13 References

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